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ON
CANE SUGAR
AND THE
PROCESS OF ITS MANUFACTURE
IN JAVA

H. C. PRINSEN GEERLIGS

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ON

CANE SUGAR

AND THE

PROCESS OF ITS MANUFACTURE IN JAVA.

BY

H. C. PRINSEN GEERLIGS,

Director of the "West-Java" Sugar Experiment Station,
Kagok-Pekalongan.

SECOND EDITION. REVISED AND ENLARGED.

NORMAN RODGER,
ALTRINCHAM.

1906.

PREFACE TO THE FIRST EDITION.

It has been suggested to me to put together for publication in a separate form whatever is of importance for the scientific director or superintendent to know respecting the management of a Cane Sugar Factory. Good manuals already exist for methods of analysis and the chemical control of the working, but hitherto no connected work on the actual manufacture of sugar from cane, as carried on in Java, has appeared.

This omission was all the more felt, because it was impossible for those who wanted to keep *à la hauteur* of this class of operations to meet with handbooks relating to it, seeing that all the foreign works on sugar, even when professedly giving a complete *résumé* of the entire industry, only contained—after whole chapters devoted to beet sugar—a few pages relating to the cane sugar industry, in which as a rule the most antiquated and incorrect ideas were put forward.

In this small work, which is primarily intended for the scientific man or the factory manager, I have only treated of the mechanical portion so far as is necessary to afford a good idea of the manner of working. With the exception of the crushing plant, the machinery for the preparation of cane sugar varies only in subordinate points from that used in the manufacture of beet sugar, so that all possible indications on this point are to be found in every handbook on beet sugar, and it would be going beyond the scope of this book to include them here.

In drawing up this introductory manual, I have, in addition to my own investigations, been glad to avail myself of the treatises published in the *Archief voor de Javasuikerindustrie*, by Messrs. C. J. van Lookeren Campagne, B. Carp., and Dr. H. Winter, and I have to thank Mr. J. H. Maronier for assistance in the description of machinery.

In conclusion, I may remark that I have done my best to give the facts, and to exclude theoretical suppositions as much as possible.

H. C. Prinsen Geerligs.

PREFACE TO THE SECOND EDITION.

As the first edition of this little work became rapidly exhausted, a second edition was thought necessary; of which opportunity I profited to thoroughly revise it and make the changes which were induced by the improvements in sugar manufacture introduced during the last few years.

So the chapters on "Constituents of the Cane," "Juice Extraction," "Clarification," "Boiling," "After-products," and "Molasses," were re-written, causing this treatise to exactly represent the present state of knowledge and manufacture in Java.

H. C. PRINSEN GEERLIGS.

PEKALONGAN,
1st May, 1902.

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ON

CANE SUGAR

AND THE

PROCESS OF ITS MANUFACTURE

IN JAVA.

INTRODUCTION.

The sugar cane, which is now cultivated in many varieties in every tropical and semi-tropical country of the world on a larger or smaller scale, came originally, according to De Candolle, from Cochin China or neighbouring lands, from whence it was brought over to China, the islands of the Indian Ocean, India, and afterwards to Arabia. In their wars of conquest, the Arabians introduced the cultivation of the sugar cane successively into Persia, Egypt, Palestine, Syria, along the whole north coast of Africa, into Sicily, and into Spain. The Spaniards transported it, after the expeditions of Columbus, to their empire in the West Indies and America, where the cultivation at once became a very flourishing one. Cook found the sugar cane in a cultivated state in the Polynesian islands, to which it had very probably been brought from Asia.

From the most remote historical times the sugar cane was used in China and in India, as a nutrient or a dainty, the cane itself being eaten or the juice sucked out from it, but no real preparation of sugar is recorded before about 600 A.D., at which period a Chinese emperor sent a man to learn the art of sugar-making in India, in which country it was already known at a much earlier period, for in the year 500 A.D. white sugar is mentioned as being shipped to Europe from India.

Although in the first 1000 years of our era sugar was imported into Europe, where it was regarded as a rare and precious article, the importation of sugar from Asiatic countries only assumed large proportions when, as a consequence of the Crusades, the trade between Europe and Western Asia became more considerable. Afterwards, when, besides the cane-growing countries already mentioned, the Spanish and Portuguese possessions in America also produced sugar, the consumption of cane sugar increased more and more, until in the beginning of the 19th century the manufacture of sugar from the beetroot in a practical way was invented in Europe. Since that time the production of cane sugar, though steadily increasing in volume, has been constantly falling behind as compared with that of beet sugar, and while it formerly represented the entire consumption, it now (1905) only amounts to 43% of the total production coming into consideration for the world's market.

The keen competition with the beet sugar, which is in these days being grown in nearly all the countries of the temperate zone, has, however, had this advantage, that the cane sugar industry, which up to a very short time ago had been conducted in a very irrational and sometimes even reckless manner, has profited by all the experience and improvements that have proved successful in beet sugar manufacture, has placed on a scientific basis the methods of cultivation and manufacture, and so has succeeded in maintaining itself, though every year with increasing difficulty, as yet mostly unprotected against the heavily subsidized competing industry.

PART I.

THE RAW MATERIAL.

CHAPTER I.

The Sugar Cane and its Constituents.

The sugar cane (*Saccharum officinarum*) is a perennial plant of the family of the Gramineae. It can be propagated by seed as well as by layers or cuttings, but in practical working only the latter way is used; the production of cane from seed being only used by scientists or by cane growers with a view to raising new cane varieties by cross-fertilization. After the new varieties are selected those which possess superior qualities are picked out and propagated by cuttings. The upper portions of the cane are almost universally regarded as the best planting material; they are cut into pieces of a foot or more in length, and planted horizontally or with a slight inclination. After a period of from seven to twenty days, varying according to the variety of the cane, the age of the cuttings, and the temperature, the buds sprout and form a young plant, which soon grows up, forms a stalk and leaves, and also sends out rootlets in the soil. After the stalk has grown up, its undermost buds also sprout and again form stalks, under which process the whole plant assumes the form known under the name of "stool."

As the canes grow older, the lower leaves dry up and fall off, which process is promoted in cultivation by the stripping or trashing, *i.e.*, removing of the dry leaves. The spot where the leaf is attached to the cane is called the knot, which remains visible as a swollen ring. On the knot is situated the bud or eye, and the part of the cane between two knots is called the joint. As the leaves gradually fall off, the ripe cane assumes the aspect of a long rod, bearing rings, and adorned at the top with a tuft of green leaves. Some canes arrow, others do not, and as yet no one has been able to detect the reason of this difference. Some time after planting, varying, according to the variety of the cane or the climate of the country, between ten and twenty months, the cane contains its maximum of sugar and must be cut. The canes are dug out, or, if it is wished to get ratoons from them, simply cut, and deprived of the tops bearing the green leaves, as the top is an excellent planting material, but if crushed along with the canes is more apt to spoil the juice than to enrich it.

In countries where the planters are owners of the land and labour is scarce, they prefer allowing a second crop to sprout from the stubble remaining after the first harvest, and can get as many as even six successive crops from the same stubble without planting again, though by so doing the crop becomes smaller and smaller every year. In other countries where the area planted is restricted and labour is abundant and cheap, only very little ratoon cane is grown, and, as a rule, the stubble is dug out after the reaping, and new fields are planted with fresh cuttings.

Among the varieties of cane planted in the large cane-growing centres, the most conspicuous are: the black cane, the Bourbon, the Lahaina, the transparent cane, the ribbon cane, and many others among the scions of seedling canes deserving special mention.

The constituents of the sugar cane, other than water, which of course forms the principal part, are as follows :—

1. CANE SUGAR OR SUCROSE.

Cane sugar is found in a great many plants, dissolved in the sap, but only a few of them contain it in such a degree as to allow of its profitable extraction. They are the sugar cane, the beetroot, the sorghum, the sugar, coco, date, palmyra, and nipah palms, and the maple tree, while the bees extract it from the flowers of many plants, but in this case it is, however, very soon converted into glucose.

Pure sucrose appears under the form of anhydrous, bright, monoclinic crystals, having a pure sweet taste and possessing a specific gravity of 1·58 at 15° C. Sucrose is freely soluble in water, and its solubility increases as the temperature rises; the exact figures relating to this will be found in Part IV. It is almost insoluble in absolute alcohol, but dilute alcohol dissolves it and this in proportion as the alcohol is more dilute and the temperature higher. Ether, chloroform and other essential liquids, and anhydrous glycerine do not dissolve sucrose. On evaporating a solution of sucrose in water or on cooling a hot saturated solution, sucrose is deposited in crystals, which are larger in proportion as the liquid in which they are formed is purer and the crystallization slower.

Solutions of cane sugar deflect the plane of the polarized light ray to the right in a degree proportioned to the concentration of the solution and the thickness of the layer of liquid through which the beam passes, this deflection being only slightly altered by changes of temperature. Much use of this property is made in sugar-mill laboratories in the determination of the sugar content of juices, sugars, etc., by means of the polariscope.

Perfectly dry sucrose may be heated for a long time at temperatures exceeding 100° C., and even melted at 160° C. without its undergoing any decomposition; but in presence of water it is decomposed at temperatures above 100° C., as shown by the dark colour it assumes, and the property it has acquired of reducing Fehling's test solution.

Sucrose, when heated for some time at its melting point, changes without any loss of weight into a mixture of dextrose and levulosan. On heating cane sugar at a still more elevated temperature it loses water and leaves behind a dark coloured body, called caramel. If we further raise the temperature, this also becomes decomposed into gaseous products and a glossy coal, which on combustion in contact with air totally disappears without leaving anything behind, provided the sucrose has been pure.

On heating sucrose solutions at their boiling point for a long time continuously, the sucrose combines with water even at the ordinary atmospheric pressure, and changes gradually into a mixture of equal parts of dextrose and levulose. Under a higher pressure, coincident with a higher boiling point, this reaction takes place more quickly, so that a sucrose solution, which when boiling at 100° C. is totally transformed after a lapse of 24 hours, is already quite changed into the above-mentioned mixture after six hours' heating at 150° C. During the transformation, 95 parts of sucrose combine with five parts of water to form 100 parts of invert sugar, as the mixture of equal parts of dextrose and levulose is called. The sugar thus transformed now deflects the plane of polarization to the left, instead of to the right, hence the newly-formed body bears the name of invert sugar, and the phenomenon itself that of inversion. When sucrose is brought into contact with dilute acids it becomes inverted, slowly at the ordinary temperature, but quickly on heating.

The action of the different acids varies considerably, and, moreover, they all act much more quickly the more concentrated they are; thus at 70° C. an addition of 10 per cent. of 30 per cent. hydrochloric acid in a few minutes inverts a solution of sucrose without causing any coloration, which property is often made use of in analysis.

The inverting power of some acids, used in equivalent quantities at 25° C., on a 50 per cent. sucrose solution may be indicated by the table underneath, where hydrochloric acid is taken as the starting point with the figure 100.

Hydrochloric acid	100	Citric acid	1·7
Nitric acid	100	Formic acid	1·5
Sulphuric acid	53·6	Malic acid	1·3
Oxalic acid	18·6	Lactic acid	1·1
Phosphoric acid	6·2	Succinic acid..	0·5
Tartaric acid	3·1	Acetic acid	0·4

Mineral acids, especially at high temperatures, along with inversion produce a still further decomposition, which is accompanied by a dark coloration, and in the end causes sucrose to be decomposed into various volatile as well as black fixed acids, the latter being classed together under the name of humic acids, but their composition has as yet been insufficiently investigated.

Alkaline bodies, such as potash, soda, lime, etc., only attack sucrose solutions when they are heated with them in a concentrated state. At a not too strong concentration they combine with the sucrose and form very soluble alkaline combinations called saccharates, which require just as much acid for their neutralization as the quantity of base present in the combination. In the formation of such a soluble saccharate, lime, which is only slightly soluble in water, dissolves on the contrary freely in a sugar solution. Like all other acids, carbonic acid also decomposes these saccharates.

Salts also, like bases, may form combinations with sucrose; in this way sucrose-sodium-chloride, sucrose-sodium-iodide, and some others are known to exist in a crystallized form, but all of these are very soon decomposed and are rather uninteresting.

Many salts, principally those of inorganic acids, have the property of inverting sugar solutions at their boiling point, which property seems not to increase in proportion with their concentration. The simultaneous presence of glucose increases this property in proportion as the glucose content rises, so that while in the beginning only very little sugar is inverted, this inversion goes on in a continually higher degree. Not only do salts with an acid reaction show this inverting power, but even alkaline salts, having a neutral reaction, and especially those which, like ammonium salts, are very liable to dissociation, or salts with feeble bases. Salts with a strong base, or salts of organic acids (which even when free are but feeble inverters), accordingly possess also a very slight inverting power or none at all, or will even neutralize by their mere presence the action of the other salts.

Sucrose is very liable to be broken up by all kinds of ferments. Well nigh all the species of yeast separate a ferment that transforms sucrose into invert sugar, which latter afterwards becomes changed by the influence of the yeast enzymes into carbonic acid, alcohol, and some by-products, causing the sucrose, as such, to disappear totally. The lactic acid bacteria transform sucrose, especially in presence of lime, into lactic acid, in which process carbonic acid and hydrogen also arise; and this process is often followed by the butyric acid fermentation, forming the unpleasant smelling butyric acid from the lactic acid, a phenomenon sometimes met with in practical working. Another lower organism, *Leuconostoc mesenterioides,* will, more especially if lime or chalk are present at the same time, convert sucrose, with formation of acids, into a thick, slimy, tough mass, which appears in gelatinous layers or lumps, and bears the name of dextran. Not only does the sucrose affected become totally lost in this way, but these lumps, by their choking up the pipes and cocks, may cause much trouble in the factory.

2. DEXTROSE.

Dextrose, besides occurring along with levulose as a product of decomposition (due to inversion) in over-ripe canes, is a normal constituent of both ripe and unripe cane, and is therefore to be found in all cane juice to a greater or less extent. It is also a very widely spread constituent of plants in general, and is manufactured commercially in huge quantities by the action of sulphuric acid on starch.

Anhydrous dextrose appears in the form of hard columnar crystals melting at 146° C., while the more common hydrate occurs in opaque crystal-crusts or in big transparent crystals with a melting point of 86° C.

Dextrose dissolves very easily in water. At 15° C. 100 parts of water dissolve 81·68 parts of anhydrous dextrose or 97·85 parts of the hydrate; in the same way dextrose is soluble in alcohol and this in proportion as the alcohol is warmer and more dilute. This sugar also dissolves in methyl-alcohol, but not in ether or acetone.

Like sucrose, dextrose deflects the plane of polarization to the right, though in an inferior degree, for if we suppose the rotation of the former equal to 100, that of anhydrous dextrose is equal to 80, and that of the hydrate to about 73, while the specific rotation rises as the concentration of the solution increases.

Variation in temperature does not influence the rotatory power within those limits which are not exceeded in ordinary laboratory work. The above figures do not apply in the case of freshly made cold dextrose solutions, as in this case the dextrose has a much greater rotatory power, which may even become twice the value just mentioned. After standing some time cold, or sooner on being heated, or made alkaline with a little ammonia, the rotation diminishes and comes back to the lower figures given above.

Dextrose, when heated above 100° C., assumes a brown coloration; at 170° C. water passes off, and the coloured residue contains, among other things, dextrosan, while at a still more elevated temperature the substance inflates, blackens, and allows a large quantity of gaseous products to escape, the rest being a carbonaceous mass, containing caramel, which, when heated in contact with the air, undergoes total combustion.

Dilute acids exercise no influence on dextrose, but concentrated strong acids break it up just like sucrose, causing formation of black humic combinations.

Alkalies convert dextrose, especially at an elevated temperature, into a mixture of dextrose, levulose and mannose. This process goes on gradually until the dextrose and the levulose are represented in fairly equal parts, while the quantity of mannose is very small. Even very feeble concentrations of alkalies or alkaline earths have this property. An addition of 5 grammes of lime to 100 grammes of dextrose dissolved in 400 grammes of water is able to change at a temperature of 70° C. the dextrose in the above-mentioned mixture within a few hours.

Apart from this reaction alkalies and alkaline earths combine with dextrose and form dextrosates, combinations of a character analogous to the saccharates already mentioned. They are, however, very unstable, as the bases act upon the dextrose after standing some time or on the temperature being raised, converting it into acids and combining with these, forming salts. The products of decomposition formed by this reaction differ according to the concentration, the temperature, and the nature of the alkali. At temperatures under 60°C. the products caused by the decomposition of dextrose are principally saccharinic and lactic acids, both uncoloured bodies, yielding salts not liable to spontaneous decomposition. Under reaction at high temperature, however, saccharinic, glucinic and melassinic acids and other dark-coloured, scarcely investigated bodies are produced, the coloured salts of which are apt to become broken up spontaneously into acetic, formic, and apoglucinic acids, causing a neutral solution to turn acid. The lime salt especially of this acid is hygroscopic, and yields a viscous solution; the solutions of the potash and soda salts of the same acid are much more liquid. Dextrose, in alkaline solution, eagerly absorbs oxygen, both free and combined, hence many metallic oxides, as chloride of gold, nitrate of silver, etc., become reduced by an alkaline dextrose solution. Cupric oxide is reduced to cuprous oxide, and this, if the conditions are always identical, in quantities proportioned to the quantity of dextrose; this property is made use of in the determination of dextrose with Fehling's test solution, in which case the content of a glucose solution is ascertained by the quantity which is required to transform all the cupric oxide of a fixed quantity of a copper test solution into cupric oxydule or cuprous oxide.

Neither neutral nor basic acetates of lead precipitate dextrose from its solution in water, but it is totally thrown down by ammoniacal acetate of lead (*i.e.*, basic acetate of lead to which ammonia is added till a precipitate is just being formed).

One gramme of anhydrous dextrose dissolved in 100 c.cm. of water and mixed with 5 c.cm. of a solution of 40 grammes of phenylhydrasin and 40 grammes of glacial acetic acid, completed with water to 100 c.cm., will yield, after being heated for one hour at 100°C., a precipitate of crystallized glucosasone. The weight of this glucosasone is, after cooling, filtering, washing, and drying, 0·32 grammes. Its fusing point is 205°, provided that care is taken to heat the sample destined for the determination of the fusing point rapidly, as in the contrary case this point will be too high.

Dextrose may, the same as with sucrose, be decomposed by yeast, and is also subject to all fermentations mentioned under that heading.

3. LEVULOSE.

In the sap of perfectly ripe sugar cane little or no levulose seems to occur, but it may be found in unripe or over-ripe canes. In unripe cane it is principally present in the parts still growing, from which it disappears as the cane ripens. In dead canes, where the sucrose has already undergone partial inversion, levulose occurs, of course, as one of the products of this inversion, just as in the juices circulating in the factory, in which also levulose has arisen by inversion to some extent.

Levulose appears in the form of rather hygroscopic needles, which melt at 95°C., and are very soluble in water and in alcohol.

It is insoluble in cold absolute alcohol, but on the other hand it is dissolved in hot absolute alcohol and in ether containing alcohol.

It turns the plane of polarization to the left, and its lævo-rotatory power exceeds the dextro-rotatory power of dextrose or sucrose; the rotation is, however, much influenced by temperature, and diminishes when the latter rises. If we again suppose the right-hand polarization of sucrose to be 100, the rotation of a 10% levulose solution is at 0°C., 152·5; at 20°C., 135·6; and at 30°C., 127·2.

On heating levulose it is soon decomposed into water and levulosan; therefore one must be very careful when drying substances containing levulose, *e.g.*, for the determination of moisture in all products of the cane sugar industry, not to break up the levulose. As moist levulose is still more liable to decomposition than dry, it is advisable to dry such substances first at 60°C., and only afterwards drive off the last traces of water at 100°C. The products arising from levulose by the action of heat, of oxydizing agents, of acids and alkalies are the same as in the case of dextrose, the only difference being that levulose decomposes more quickly than dextrose.

Neither neutral nor basic acetate of lead throw down levulose from its solution in pure water, but the last-mentioned reagent precipitates this sugar in part as soon as salts occur in the same solution, with constituents of which basic acetate of lead forms insoluble combinations. When, in this case, a precipitate of a lead salt is formed, this carries down a part of the levulose as a plumbic salt. For this reason clarification of levulose, containing juices or solutions with basic acetate of lead, is not adequate when it is necessary to determine the glucose content in the filtrate.

When heating one gramme of anhydrous levulose dissolved in 100 c.cm. of water for an hour with 5 c.cm. of the above mentioned phenylhydrasin-glacial acetic acid mixture, the same glucosasone, as in the case of dextrose, is precipitated but its quantity is 0·70 grammes. The fusing point of the glucosasone is of course again at 205° C.

In practical working the custom is to summarize the dextrose as well as the levulose and the mixture of both known under the name of invert sugar, under the common name of glucose, and to determine by analysis the amount of this constituent from the quantity of copper oxide it reduces, without making any distinction between the kinds of sugar of which it is composed. Wherever in the present treatise the term glucose is used, it always means that sugar or mixture of sugars which has the property of reducing Fehling's test solution.

The mixture of glucoses, formed by the inversion of sucrose, consists of equal parts of dextrose and of levulose, and considering that levulose turns to the left in a higher degree than dextrose to the right, the mixture is sure to possess a left-hand rotation, diminishing like that of levulose as soon as the temperature rises. If we again suppose the figure 100 to represent the dextro-rotation of sucrose, the rotation of a 20% solution of invert sugar is at 0° C.,-36·4; at 20° C.,-27·9; and at 30° C.,-23·7; while it ought to be borne in mind that in this case also the concentration of the solution is not without an influence on the specific rotatory power.

4. Organic Acids.

The organic acids of the sugar cane are glycolic, malic, succinic, tannic, and in dead cane (as a product of decomposition) also acetic acid. Some investigators report having also detected citric, tartaric, and aconitic acids, but these statements have as yet not been confirmed. In ripe canes the quantity of organic acid is only very trifling, and does not exceed 0·15%, of which quantity 0·06% is present as free acid, and the rest combined with alkali.

Glycolic acid occurs among other constituents in unripe grapes, and is also detected in beet juice bottoms, after the juice has been heavily limed and subsided. Its lime salt is soluble, therefore the acid is not removed by clarification, and it may be traced in the molasses in so far as it has not become decomposed during manufacture.

Malic acid is found in a great many fruits and juices; it is a very stable acid and does not get broken up in the course of manufacture, its lime salt is soluble in water, so that the acid is not removed by defecation of cane juice with lime.

Succinic acid is, like malic acid, a very stable acid, and like it possesses a soluble lime salt.

Acetic acid is only to be found in dead or diseased canes as a product of the decomposition of the sugar. Its lime-salt is soluble, and therefore remains in the juices after liming; it has the awkward property of being very hygroscopic, and this is the reason why sugar yielded by damaged or dying canes often becomes moist again after being well dried.

Tannic acid of unknown composition occurs in very trifling quantities in young canes and in the green tops of ripe ones. The quantity is somewhat insignificant, and it combines with albumen immediately after the crushing, forming an insoluble precipitate, thus it does not interfere with the further manufacture. The acids mentioned here are originally from the cane and pass over into the juice, but during manufacture such large quantities of organic acid are produced by the action of lime on the glucose, that the acids from the cane have only a very subordinate importance. As we have already seen, they differ according to the temperature and bear the names of lactic, saccharinic, glucinic, and saccharic acids, etc.; their properties have been described above.

5. Nitrogenous Bodies.

Ripe sugar cane contains very little nitrogenous substance, only the leaves and the green tops contain a rather considerable quantity, but in the ripe cane itself only the buds are provided with it. A perfectly ripe cane, without the leaves, contains an average of 0·05% nitrogen, and the whole plant, without the roots, up to 0·08%.

Juice filtered through cloth was found to contain from 0·018-0·062% of nitrogen, being 0·036 in the average, and of this small amount a considerable portion was not dissolved, but in the form of a colloid, for the amount of nitrogen decreased greatly after filtration through filter paper.

By far the greatest part of the nitrogenous substance in sugar cane consists of albumen, which occurs in unripe cane to a much greater extent than in ripe cane. The nature of the albumen, or kinds of albumen, is not yet known.

Besides albumen the presence of amides or amido acids has been proved, but as yet no conclusive evidence has been obtained as to whether these are asparagine, aspartic acid or glycocol. At any rate their quantity is trifling, amounting to about 0·05% of the weight of the cane.

Finally, small amounts of xanthine bases, chiefly guanine, are isolated from cane juice.

6. Colouring Matter.

In the peripheric strata of the rind of the sugar cane we find cells containing the colouring matter, which causes the different colouration of the cane. Besides chlorophyll, which in every case forms the ground colour, the presence of anthocyan has been detected in black and purple canes. When the canes are crushed, the colouring matter passes over into the juice and imparts its colour to it; thus the juice from black cane is much darker than that from white or yellow.

Next to this we find in the cane another colouring matter with which the fibre is impregnated. This is colourless in a neutral state, but becomes yellow on contact with alkaline liquids. It is so firmly connected with the fibre that it is impossible to remove it totally by extraction.

The colouring matter, the composition of which is still unknown, is very sparingly soluble in water, better so in alcohol; but it is insoluble in ether. When exposed to the air it changes into a red colouring matter, which is frequently met with in diseased or dead canes. On further oxidation, the colouring matter is broken up into a dark brown substance.

7. CANEWAX.

On the outside of the rind of the cane, especially near the knots, we find a more or less considerable layer of wax, which is more conspicuous in some varieties than in others. This wax melts at 82° C., boils at 146° C., is insoluble in water and in cold alcohol, slightly soluble in cold ether or chloroform, but dissolves easily in hot alcohol, ether and chloroform, and in benzine. It is not a wax properly so called, but a saturated alcohol, having 24 atoms of carbon.

8. PECTINE.

We always find some pectine in cane juice, in some varieties more than in others, though the composition of the soil also seems to influence its occurrence.

Pectine is only partially removed by the defecation, and more so, but even then not entirely, by the carbonatation processes, and therefore it may be expected in the clarified juice and in the molasses. Pectine is insoluble in acidulated alcohol, and does not yield sugar on being heated with dilute acids. Its lime salt is only sparingly soluble in water, but it is not quite insoluble.

On evaporating 5 grammes of pectine from cane juice with 60 c.cm. nitric acid of a specific gravity of 1·15, about 1 gramme of mucinic acid is obtained, corresponding with a content of about 30% of galactane groups in the pectine.

9. FIBRE.

All fixed substances of the cane, not belonging to the juice, is summarised under the name of "cellulose" or fibre. The first mentioned name is not correct, since the fibre only consists of 70% of properly speaking cellulose. This cellulose is incrusted with a gummy matter, called wood gum or xylan, which is firmly attached to it, and increases in quantity as the cane ripens. The cellulose itself is also slightly soluble in hot water or in dilute acids. This solubility diminishes, however, in proportion as the canes grow older. An ammoniacal solution of cupric oxide dissolves the cellulose almost entirely; whilst hydrolysis by sulphuric acid converts it into dextrose.

The wood gum or xylan occurs to the amount of 25-30% in the fibre. It is slightly soluble in water and in ammonia, better in limewater, and very much so in caustic soda solutions. The addition of acid and alcohol causes it to be precipitated as white voluminous flocks. It deflects the plane of polarization strongly to the left, and is well nigh quantitatively changed into xylose by boiling with dilute acids. On distillation with hydrochloric acid of 1·06 specific gravity it yields 80% of furfurol. Xylan is precipitated from its aqueous solution by excessive quantities of lime and barytes and by basic acetate of lead.

Owing to the fact that hot water, and thus equally hot juice, extracts parts of the gummy matter from the fibre, the determination of the fibre-content in sugar cane and in bagasse by extraction with boiling water is apt to yield erroneous (inferior) figures for that constituent.

Equally, every defecated cane juice is sure to contain more or less of this gum, especially when the juice contains many fine particles of bagasse, or the steamed scums have been treated with carbonate of soda. The large dose of lime used in the carbonatation process on the contrary throws down the major part of the dissolved cane gum.

Through the presence of the gum, which is saturated with water, the fibre may contain as much as 20% of colloid water of hydration, not belonging to the proper cane juice.

As a rule it still contains 0·7% of albuminoid matter and 3% of incombustible or ash, besides the already mentioned colouring matter, assuming a yellow colour when put into an alkaline medium.

The total quantity of fibre is tolerably regular, between 10% and 12% of the weight of the cane for the black Java cane. Other varieties may contain considerably more or less.

10. INCOMBUSTIBLE MATTER OR ASH.

Sugar cane is a plant that absorbs very little mineral substance from the soil, which is very clearly to be deduced from the trifling quantity of ash contained. The constituents vary in quantity within rather narrow limits, according to the quality of the soil, the manuring, and the variety of the cane, but all of them are found in every cane ash. The few figures underneath may be regarded as fair examples:—

Constituents.	On 100 cane.	On 100 parts of incombustible.			
	1.		2.	3.	4.
Potash..	0·153	23·0	12·56	25·63	7·66
Soda..	0·010	1·5	5·67	2·26	6·45
Lime	0·018	2·7	5·50	3·24	12·53
Magnesia	0·014	2·1	5·08	3·22	6·61
Oxide of iron	0·003	0·5	—	—	0·56
Silica	0·351	52·8	56·76	53·42	43·75
Sulphuric acid	0·016	2·4	2·60	0·53	16·53
Chlorine	0·002	0·3	0·20	0·92	0·21
Phosphoric acid..	0·098	14·7	10·63	10·78	5·45
	0·665	100	100	100	100

1. Lockeren, Campagne, s.v.d. Veen Archief, 1895, 533.
2 and 3. Bonâme, Sugar Cane, 1894, 622.
4. Popp Krüger, Part II., 161.

CHAPTER II.

Distribution of the Constituents in the Cane.

It is evident that the above-mentioned constituents are not to be found in the same proportion in every part of the cane, as this is not to be regarded as one homogeneous mass but as a living organism, every part of which has to fulfil its special functions, and has therefore a constitution differing from that of the other parts.

The outermost part forms the rind, which is generally covered with a layer of wax of varying dimensions and also contains the colouring matter which imparts the colour to the cane. Anatomically speaking, the interior portion of the cane consists of parenchyma and fibrovascular bundles, which latter run through the cane in a longitudinal direction and end in the leaves or the buds; they are wrapped up and covered by the parenchyma. This consists of cells, which are composed of a cell-wall, protoplasm, and the vacuole, containing the saccharine juice, whilst the bundles have much thicker cell-walls and possess a very poor or almost sugarless sap. As in some parts of the cane the bundles are present in a greater proportion than in other parts, the content of fibre, sugar, and water is of course also variable for the different parts of the cane. Thus the periphery contains more fibre than the centre and less sugar or water, while the woody lower end is poorer in saccharine matter than the succulent higher joints, &c.

But the juice of all the cells is moreover far from being of a uniform composition, the younger portions containing more glucose and less sucrose than the older ones, causing the top end to be poorer than the middle or even the lower end. In the younger portions the glucose predominates, but changes into saccharose with the advance of maturity, though this phenomenon is counterbalanced by the fact that when the cane is over-ripe or dying, the sucrose in the oldest joints is again partially converted into glucose by inversion.

Apart from the juice in the vacuoles, which contains no more than sucrose, glucose, a little salts and the organic acids, the protoplasm consists for the main part of water, and this latter also contains albumen and salts; moreover, the water of the fibrovascular bundles also holds some salts in solution. Properly speaking, the cane contains no less than three kinds of juice: those of the vacuoles, of the protoplasm, and of the fibrovascular bundles, of which the first and the last contain their constituents in a dissolved state, while that of the protoplasm moreover carries matter with it in a state of suspension. The softer elements of the cane possess the purest and richest juice, so that this is at once extracted by a gentle pressure; on crushing heavily the protoplasm is rubbed to a broth, mixes up with the juice first mentioned and with that of the bundles, and yields a turbid, impure mixture.

This explains the fact that cane crushed in a weak mill yields a richer and purer juice than that crushed by a heavy and powerful mill.

The relation of the various constituents of the cane differs considerably, but for sound ripe cane it varies between the following limits:—

	Per cent.		Per cent.
Sucrose	12	to	18
Glucose	0·4	,,	1·5
Fibre	10	,,	12
Ash	0·5	,,	0·9
Undetermined	0·5	,,	1·0
Water	70	,,	77

PART II.

SUGAR MANUFACTURE.

CHAPTER I.

Extraction of the Juice.

The oldest way of extracting the juice from sugar cane, which at the same time is up to now the most usual one, is the milling process. Formerly this was performed on a small scale by crushing cane between two wooden or stone cylinders, but at present cane is crushed, in practical working, between iron or steel rollers, driven by steam or water. Formerly the cane was crushed only once, and the extracted juice boiled into sugar, but as the bagasse still contained rather a considerable quantity of saccharine juice, which was lost, the custom now is to crush the bagasse from the first mill again between a second and a third set of rollers, so that triple crushing is at present met with everywhere.

The most common form of sugar mill is the three-roller mill, of which two rollers on the same level turn in the same direction and bear the names of "feed roller" and "bagasse roller," while the third, the "head roller," is placed above the other two and turns in an opposite direction. Generally the rollers of the first mill are placed in such a way that the space between the feed and the head rollers is such that the cane enters easily and is but slightly squeezed, but the space between the head and the bagasse rollers is so small that only the crushed cane fibre can pass, causing the proper crushing to take place there. The extracted juice flows along the cylinders into a gutter placed below the mill, and the bagasse is thrown out by the rotation of the cylinders. In order to ensure good feeding and to carry the canes straight between the rollers, a metal plate, the trash or bagasse turner, is constructed, which in some systems is movable, in others fixed. The proper adjustment of the bagasse turner is one of the principal points in the milling work, and like the adjustment of the rollers requires the continual attention of the engineer.

In this treatise, which is especially destined for the chemist, it would not be in place to enter into detail on the subject, hence the following remarks may be sufficient. The proper position of the rollers, *i.e.*, the space between the feed roller and the head roller, and between the latter and the bagasse roller, depends entirely on the amount of cane that should be worked up in twenty-four hours with a given velocity of the mill, and on the quantity of juice that is allowed to remain in the bagasse, according to the capacity of the factory. These conditions being stated, the adjustment of the bagasse turner depends on them, and this ought to be changed as the mutual distance of the rollers changes.* This point dominates the mill-work and regulates the work so as to cause the maximum of cane to be crushed in a given time, whilst the accurate adjustment of the trash turner prevents the jamming of cane fibre between the rollers and diminishes considerably the breaking of axles, standards, and wheels. The distance between the bagasse turner and the bagasse roller is regulated according to the purpose the mill is used for; it is larger in the first mill, where only canes are crushed, than in the second or third, where the already finely divided bagasse has to be exhausted. As a rule, the rollers of the first mill make from 2 to 2½ turns per minute, those of the second mill 1½ to 2, and those of the third not more than 1½ or 1¾.

Besides the three-roller mills, two-roller ones are also used, the rollers of which are placed one above another, and the cane is introduced between them by means of a cane carrier; moreover, we find mills having four or eight rollers, but, as already remarked, the three-roller mill is the most common form.

In order to relieve the mills, and with a view to crush more cane in the same time with a given power, two new contrivances have lately been introduced, intended to divide the cane into small pieces before its entering the mill. They are the Ross cane-cutter and the cane-shredder. The former cuts the cane in pieces of about four inches and afterwards divides it into thin slices, while the latter reduces the cane to fibre between two rows of teeth and carries it to the mill. If the knives of the cutter and the teeth of the shredder are sufficiently sharp, this can be effected without any loss of juice; the divided cane is afterwards crushed in the same way as the canes themselves, by mills, the rollers of which must be further apart than in the case of entire canes, because they receive them in a more voluminous form.

A third engine, the "crusher," consists chiefly of a set of rollers provided with V formed teeth, which are placed so close together that the canes passing through them are slightly squeezed, and therefore the first mill can crush them more easily than the ordinary cane. Contrary to what has been observed when speaking of the former two contrivances, this one extracts a part of the juice.

When using double or triple crushing, it is advisable to use the most powerful mill as the first mill, so that it may express 60 to 65% of juice on the weight of the cane, leaving only 25 to 30% of juice in the bagasse. This is transferred by bagassse carriers to the second mill, in which the distance of the rollers is smaller than in the first one, causing the bagasse to undergo a heavier pressure and to part with a further portion of its juice. After this the bagasse is again crushed in a third mill of the same dimensions as the second, which would therefore not do any work if maceration were not applied between the second and third mill. However heavily cane may be crushed it is still impossible to express the last remnant of juice, and the residuum will of course contain sugar, being the original cane juice. When water is poured on the bagasse this juice gets diluted, and after crushing the bagasse to its former content of juice, it will then contain the same amount of diluted, but therefore less saccharine juice, causing less loss of sugar, so that maceration considerably improves the juice extraction.

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*The construction and adjusting of the bagasse turner are described further on in Part IV.

Cane that has been crushed once, or in most factories even twice, and thus has lost a great deal of its juice, is macerated at the moment that the bagasse oozes out from between the rollers, and, relieved from the heavy pressure, expands by its own elasticity and eagerly absorbs water. By the crushing in the mill the cell-walls have already been torn, allowing the maceration water to at once dilute the still remaining juice; further water is poured on the partially exhausted bagasse on its way from one mill to another, and it is moreover turned again in some factories, causing the juice which is expressed by the next mill to be highly diluted. A calculation will make this point clear. Suppose that in a factory having triple crushing a maceration of 15% on the weight of cane is applied after the second mill on bagasse of cane that has already lost 72% of juice and therefore still contains 18% of juice on the weight of cane, and that the third mill squeezes this macerated bagasse again to the same content of juice as when it left the second mill, the following is the result, assuming that juice and maceration water have been completely mixed in the bagasse: The bagasse contained 18% of juice; water was added to an amount of 15%, therefore the macerated bagasse contained $18 \times 15 = 33\%$ of diluted juice, of which $\frac{18}{33}$ is original, undiluted juice. Now the third mill expresses the bagasse again to 18% of juice on the weight of cane, causing 15% of diluted juice, corresponding to $\frac{18}{33} \times 15 = 8{\cdot}2\%$ of original juice to be extracted, which without maceration and recrushing would have been lost.

It is true that in the short time that the bagasse requires to pass from one mill to another the maceration water cannot mix up completely with the juice still remaining in the bagasse; a mixture of 80% is very satisfactory, and owing to this the diluted juice extracted by the last mill does not contain so much sugar as is calculated here.

Supposing a mixture of 80%, then 80% of the juice in bagasse or $\frac{18 \times 80}{100} = 14{\cdot}4$ parts of original juice mix up with 15 parts of water. These 29·4 parts of diluted juice contain each $\frac{14{\cdot}4}{29{\cdot}4}$ parts of original cane juice; therefore the 15 parts of juice extracted contain $\frac{14{\cdot}4}{29{\cdot}4} \times 15 = 7{\cdot}35$ parts of original juice, instead of the 8·2% which would be the case if the maceration water had become totally mixed with the juice in the bagasse.

In many sugar factories the bagasse is macerated between the first and second mills with the diluted juice from the last mill, and with pure water between the second and the last mill. All the juice coming from the last mill is poured over the bagasse from the first mill, and the juice from the first and second mill is conveyed into the clarifiers. This maceration with last mill's juice can only be applied if the cane is crushed so heavily in the first mill that the first bagasse can easily absorb liquid. A feeble first mill only squeezes the canes, and they leave it with a smooth surface and are unable to absorb the last mill juice. In this case this saccharine liquid is again extracted by the second mill without having diluted the juice in the bagasse, or it soaks through the planks of the carrier on to the floor and is consequently lost.

By the work of the cane-preparing apparatus, such as cutters, shredders or crushers, it is feasible to obtain the first mill's bagasse in such a spongeous condition that it eagerly absorbs the last mill juice, and therefore contains, after leaving the second mill, a more dilute juice than when the maceration with last mill juice has been omitted, or when that juice has only moistened its surface and has not penetrated into the interior of the layer of bagasse on the carrier. It is evident that the cane-preparing machines not only allow quicker working and decrease the risk of break-downs, but for the above-mentioned reason also bring along a better juice extraction while maintaining the same dilution.

It is advisable to pour the last mill juice on the bagasse by means of an open gutter and not through a perforated tube, as is the custom with maceration water. Notwithstanding the fact that this juice passes through copper strainers it may carry along fine particles of bagasse, which might choke up the openings of the supply tube. The best thing is to allow the juice to flow over the brim of an inclined open gutter placed over the bagasse carrier.

As to the amount of juice extracted, it matters little whether hot or cold maceration water is used. Hot water has the disadvantage of dissolving more gummy matter from the bagasse and bringing it over into the juice, but still it is to be preferred from a practical point of view. The cold water used for the purpose in sugar mills is ordinarily dirty and needs filtration, therefore likewise with a view of preventing the choking up of the apertures in the supply pipes or in the "Streudüsen" it is better to use the condensed water from the hot well. As it is an advantage to spread the water with force on the bagasse, the maceration supply is generally connected with the feed pump of the boilers. In this simple way one obtains without special machinery a steady supply of hot water under considerable pressure.

This process of continuous maceration and extraction, however, has its limits, as it is not economical to go on in this way in order to extract all the sugar from the cane, as in this case the cost of evaporating the huge quantities of maceration water would exceed the yield of the extra sugar thus obtained. Moreover, by the action of the repeated maceration and crushing, all kinds of bodies are extracted from the fibre and go over into the juice, causing it to become more impure and more troublesome to clarify. It is advisable for every factory to regulate the mill work according to the water and sucrose content of the last bagasse, and to regulate the maceration by the specific gravity of the last mill juice. The more powerful the mills are the more work may be claimed of them, and the drier and more exhausted the bagasse may be expected to be, without being subject to fixed rules, so that no exact figures can be given here on this point. Factories possessed of a large evaporating plant and of sufficient steam may go farther with maceration than those where stoppage in the course of working, owing to want of capacity, is to be feared. Besides this, copious maceration will be more in place when crushing cane with juice of a high saccharine content, than in cases where poor cane has to be worked up. In any case the extent of the maceration is, however, to be regulated by taking care to maintain the diluted juice from the last mill at the same specific gravity. When crushing canes having a rich juice, more maceration water will be required to dilute the last portions of it to the fixed specific gravity than when a cane with a poor juice is crushed, and thus the maceration is regulated by the constant testing of the last mill juice by the Brix hydrometer, and so always obtaining bagasse containing juice with an invariable quantum of dry substance. Owing to the circumstance that the Brix hydrometer only ascertains the quantity of dry substance and not that of sucrose, the sucrose amount of the bagasse cannot be regulated in the same exact way, but the proportion between dry substance and sucrose does not differ so much in the same factory that any great mistake can ensue. If care is taken that the mills always crush with a uniform power, and the resulting bagasse therefrom contains a constantly identical amount of water (juice), then, owing to the uniformity of the last mill juice, the sucrose content of the bagasse is also always the same within certain limits, which gives great regularity to the work. The quantity of juice extracted from 100 parts of cane now depends only on the amount of fibre in the cane, and this quantity diminishes for two reasons when the amount of fibre rises. Firstly, cane with much fibre contains a proportionately smaller quantity of juice; and, secondly, the quantity of bagasse is increased, and hence also the quantity of juice which it contains and that of the sucrose in it which is to be eliminated.

We do not, even with the best and most powerful mills, succeed in expressing more than 90 to 94% of the sucrose of the cane, the result being that the balance of 10 to 6% is consumed in the fuel,* while at the same time the heavy pressure causes a great quantity of impurities to pass over in the juice. This, as well as the example of the beet sugar industry, induced the planters to try to substitute the diffusion process for the mill, but this has as yet not met with general approval.

The principle of diffusion is based on the property which many bodies possess, when in solution, of passing through a membrane, if on the other side of it a liquid is present containing a smaller quantity of the like body in solution, this process going on until a state of equilibrium is attained between the liquids on each side of the membrane. The bodies having this property are principally those capable of becoming crystallized, so-called crystalloids, while gummy and albuminoid matters, so-called colloids, diffuse very slowly or not at all. In the living cell the protoplasmic tegument of the cell wall cannot be regarded as a dialytic membrane, but as soon as the cell is killed by heat, or in some other way, the protoplasm becomes pervious.

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* In former years when the methods and mills were not so perfect as they are now, the amount of sucrose remaining in the bagasse was larger; losses of 12% of sucrose in cane were formerly no exceptions.

In practical working, diffusion is conducted by slicing canes in chips by means of slicing machines, and transferring the chips into large vessels called diffusers, where hot water is poured on them, causing the cells to die, and sucrose, glucose, acids and some incombustible matter to pass through the cell walls until the consistency of the juice inside and outside of the cells has become the same. Afterwards the water, or more properly speaking, the diffusion juice, is drawn off and poured upon a fresh quantity of slices, when it becomes still further enriched, and this process is repeated until the amount of sucrose in the diffusion juice has reached as nearly as possible that of the original cane juice. The slices that have been partially exhausted by the most concentrated juice have more dilute diffusion juice poured over them, and finally water, and are totally exhausted, which operation, now that the cells are dead, may be effected without applying heat every time. Eventually, the slices, which during all this time have remained in the same diffuser, have successively been in contact with a diffusion juice of high concentration, heated with steam to kill the cells, afterwards with more dilute juice and finally with water, so that when they are removed from the diffusion battery by opening the bottom of the diffuser they have a minimum content of sucrose.

The technical part, *i.e.*, construction and treatment of the diffusion battery may remain undescribed here, because it is the same as has already been frequently described in all the handbooks on the beet sugar industry. It may just be mentioned that the most advantageous way of heating is by steaming the diffuser filled with fresh chips to a temperature of 90° C., and not warming the others. At this temperature the cells die, and the sucrose diffuses, whilst albumen coagulates. After the diffusion juice is drawn off, its place is taken by juice which has been in contact with previously heated chips and hence has a lower temperature, and this goes on until the exhausted chips leave the diffusion battery with the same temperature they had when entering into it, so that in the chips no heat becomes lost. Nevertheless experience has shown that with this mode of working almost all the sucrose of the cane is extracted, while at the comparative low temperature prevailing in the battery, no inversion takes place and no organic substances are decomposed. In the process of cane diffusion, glucose diffuses the fastest, then sucrose, and afterwards some incombustible matters; albumen, colouring matter, pectine, etc., which cannot pass through the cell wall, are to be found in small quantity in the juice, owing to the fact that the cells which were damaged in the slicing have poured out their total contents in the juice.

The following table shows the composition of the juice in the different vessels of a diffusion battery:—

No. of the Vessels.	Brix.	Sucrose.	Glucose.	Insoluble in Acidulated Alcohol.	Incombustible.	Not determined.	Quotient of purity.	Glucose ratio.	Ash ratio.
Cane juice ..	18·33	16·14	0·81	0·283	0·290	0·81	89	5·2	1·9
1..........	12·6	10·74	0·58	0·117	0·170	1	85·2	5·4	1·6
2	10·21	8·59	0·40	0·103	0·162	0·96	84·1	4·7	1·9
3....	7·1	5·95	0·25	0·085	0·135	0·68	83·8	4·2	2·3
4..........	5·5	4·71	0·17	0·062	0·120	0·43	80	3·6	2·5
5	4·4	3·71	0·15	0·067	0·109	0·36	84·3	4	2·7
6....... ..	3·4	2·82	0·12	0·061	0·101	0·30	82·9	4·3	3·6
7..	2·81	2·26	0·08	0·058	0·085	0·33	80·6	3·6	3·8
8	2·4	1·89	0·08	0·043	0·079	0·31	75·4	4·3	4·2
9..	1·9	1·42	0·04	0·030	0·081	0·33	74·7	3	5·7
10	1·6	1·24	—	0·020	0·070	0·27	77·5	—	5·7
11..........	1·2	0·99	—	—	0·054	0·16	82·5	—	5·5
12	0·8	0·39	—	—	0·043	0·37	49	—	11
13	0·5	0·28	—	—	0·031	0·19	56	—	11
14	0·39	0·31	—	—	0·013	0·08	70	—	4

The contest between diffusion and milling becomes more and more decided in favour of the latter process, which is principally due to the many improvements made in the mills and cane preparing apparatuses in the last few years. The extraction by means of mills is no longer so inferior to diffusion work as it used to be. Further, the construction of the mills is much improved too, causing breakdowns to occur far less frequently than before and to be repaired much more quickly than in former times. Finally, the introduction of cutters and shredders has contributed considerably to ensure a more regular working of the whole milling plant.

A great advantage of mills is that their capacity permits more variations of output than is the case with the diffusion battery. If necessary it is possible (when, for instance, burnt cane must be crushed at once) to crush 600 tons a day with a milling plant intended to crush, say 450 tons, provided the other stations of the factory can tackle and work up all the juice. It is evident that such an enormous increase of work done cannot but influence its quality, so that a poorer extraction will be the consequence; and granting even this, we must not overlook the fact that a diffusion battery may conceivably accomplish such excess of work. But even if we allow a very poor extraction it would not be feasible to work up all the canes, as the slicing machine might prove insufficient to properly slice all the surplus cane. On the other hand, the advantages of diffusion are that it extracts nearly all the sugar from the cane in the form of a pure juice, the greater part of the impurities remaining behind in the bagasse, so that the juice is easily workable. There is also less danger of stoppage from breakdown, for if one diffuser gives way it is disconnected and the work carried on with the others, which is not so feasible with mill work.

The disadvantages are that more hands are required by the diffusion system, and that they must be chiefly workmen acquainted with diffusion. Moreover, the diffusion juice is very much diluted (up to 20% and sometimes beyond), and a large quantity of steam is required to evaporate the diluting water. It is true that in some factories working with the mill the dilution by maceration is not less than 20%, but only in case they are crushing canes with a high saccharine content which renders such dilution worth the while; on the other hand, it is not possible in diffusion to diminish the dilution in the case of poor cane, so that poor and rich juices are equally highly diluted. Finally, the slicing machine costs a great deal in steam and maintenance, as it has very heavy work to do in cutting up all the hard cane into thin slices, and the exhausted slices contain so much water that they have to be freed from the excess by means of a mill before being dried in the sun to form serviceable fuel. Naturally the mill has nothing like so much to do as when it is used for cane crushing, but still it is a great inconvenience to be obliged to have a mill apparatus along with the diffusion battery. Then the bagasse, which is first cut and then ground and dried, is much finer and more powdery than cane bagasse, which has only been ground, and it supplies a less valuable fuel. Against the advantages of extracting more sugar and having a pure diffusion juice, along with regular working, we have thus to put the disadvantages of requiring more, and also more skilled, workmen, being compelled to use more steam, and getting a less valuable fuel as an after-product, whilst the capacity of the station does not adapt itself so well to a decrease or increase in the quantity of cane to be worked up as with a milling plant.

Finally, at every stoppage of the diffusion battery, we have to face the problem of what to do. Work off the whole battery and gain as much as possible at the cost of a huge dilution, or stop adding water when the cane is only halfway exhausted.

Ordinarily one chooses a compromise between the two alternatives and thus has at each stoppage a considerable loss of saccharine matter as well as a great dilution which costs much valuable fuel. As the cane is not in store as beetroots are in Europe, and the supply may be very irregular in rainy weather, this drawback connected with stopping a diffusion battery is of a much more serious character than in Europe, while stopping does not affect the milling work.

CHAPTER II.

Composition of the Juice.

As has already been observed, the composition of cane juice as expressed by the mill is quite different from that obtained by diffusion, the latter containing considerably less impurities. Cane juice, as it comes from the mills, is an opaque liquid, covered with froth, owing to the imprisoned little air bubbles it contains, and having a coloration varying according to the colour of the cane from which it has been expressed, from grey to dark green. It contains in solution all the soluble constituents of the cane, such as sucrose, glucose, salts, organic acids and pectine, and in suspension, besides the air already mentioned, fine bagasse fibres, sand and clay (adhering to the cane), and colouring matter and albumen, which latter body also occurs in solution in case unripe canes or green cane-tops have been crushed together with the ripe canes. Fresh mill juice has an acid reaction and owing to the presence of pectine and albumen is a viscous liquid that cannot be filtered when cold, hence the suspended constituents cannot be removed without steaming, and we have therefore to be content with keeping back the larger particles of bagasse by copper sieves before the juice is worked up. The proportion in which the chief constituents occur in the juice is very different, and depends, among other things, on the variety and age of the cane, the nature of the soil, the manuring, the climate, and even on the power of the mills. In the main, the figures for sucrose and glucose show the greatest differences, while on the contrary the other elements, at least in sound and ripe cane, do not vary much; in dead or unripe cane these figures also show great differences, and especially in the former case the amount of acid will increase considerably. Apart from the difference between the juice of various kinds of cane, the same quality of cane may yield juice of a different composition according to the degree of pressure it has undergone during the crushing. With heavy pressure the increase is principally in the amount of constituents of the cell-wall and the protoplasm, whilst the saccharine matter either remains unchanged or diminishes, causing the juice yielded by the second or third mill to be more impure than that of the first, though as a rule their glucose content is inferior. This phenomenon is easily explained when we remember the anatomical structure of the cane. The saccharine juice, which, as has previously been shown, does not contain, besides water and sucrose, anything but a little glucose, ash, and incombustible matter, is enclosed in cells, the woody walls of which are covered inside with a semi-liquid protoplasm. A gentle pressure causes the cells to split and bursts the walls, allowing the pure juice to flow out; with a heavy pressure, however, the juice is commingled with the protoplasm, at the same time the soft elements of the fibre are loosened, and so a kind of diluted broth flows from the mills instead of a clear juice. Maceration dilutes this broth still further, and facilitates its expression, which explains why the later juices contain more carbo-hydrates insoluble in alcohol (summarized under the name of pectine) than the first mill juice. Moreover the hard, woody rind is only broken by the heaviest pressure, hence the second and third mill juices are much darker coloured than the first. The only thing that seems improbable at the first view is that the first mill juice is richer in glucose than the later ones, but this fact is only to be ascribed to the top of the cane being at the same time the softest part and also containing the most glucose. Gentle pressure therefore expresses this part easily and this imparts to the first juice proportionally more glucose than to the other juices in which principally the juice of the older parts is represented.

A good example showing the difference of cane juice extracted by a series of three mills from a similar sample of cane without maceration is given here.

Constituents.	1st mill.	2nd mill.	3rd mill.
Brix..	19·2	19·3	19·0
Sucrose	16·49	16·33	15·95
Glucose	1·98	1·57	1·52
Ash	0·28	0·41	0·42
Gum and Pectine..	0·125	0·376	1·250
Albumen	0·025	0·092	0·054
Free Acid	0·048	0·072	0·096
Quotient of purity	85·9	84·4	84·0
Glucose ratio..	12·1	9·6	9·5
Coloration	light	dark	very dark

As a matter of fact, diffusion juice does not show similar differences, firstly because only one juice is obtained, and secondly because but few cells are opened. The diffused juice, properly so called, is free from albumen and pectine, but as the slicing machine cuts through a certain number of cells, their contents are poured out into the juice, so that in practical working diffusion juice is sure to contain a small quantity of pectine, colouring matter and albumen. On the other hand, the hot water of the diffusion battery dissolves a little of the gummy matter of the cane fibre, causing the diffusion juice to contain more gum than a mill juice. Neither enclosed air bubbles nor bagasse fibres are met with in the diffusion juice, at the same time the amount of sand and clay carried along with the juice is also trifling. Another advantage of this juice is that it can be much more accurately measured, because the surface of the liquid is flat and not covered with froth as mill juice usually is.

CHAPTER III.

CLARIFICATION.

The first operation that cane juice undergoes is that of clarification, which removes the impurities as far as possible, destroys all substances producing sourness and causing deterioration, and thus prevents the loss of sugar. This ought to be performed as quickly as possible, in order to allow the clarified juice to be concentrated without much delay, as it is only in concentrated solution that sugar is capable of resisting the action of ferments or micro-organisms.

Excepting heat, which coagulates the albumen, the agent which from the earliest times has been used for clarification, and which still maintains its ground, although a great many other clarifying agents have been recommended as substitutes, is lime, which has the advantages of being very suitable for the purpose, of being cheap, and obtainable everywhere. The methods of clarification may be divided into two distinct classes, viz., defecation and carbonatation, which may be applied in various ways. In defecation only a small quantity of lime is used, so that very little or no excess of lime remains after clarification, while in the carbonatation process the juice is heavily limed and the excess afterwards removed by carbonic acid.

I. DEFECATION.

1. *Heating. Liming. Settling.*

The quantity of lime used in the defecation process is just sufficient to neutralize the free acids of the juice, preventing them from afterwards causing inversion; further, the lime combines with the albumen, which had previously been suspended in the juice in a gelatinous form, but is now coagulated both by the action of lime and of heat. The acid calcium phosphates are precipitated as flocculent tribasic phosphate, as well as a part of the pectine. All these flocculent precipitates envelop the suspended particles of bagasse, the wax, clay, &c., and after being heated to its boiling point the juice is divided into a clear limpid liquid and thick frothy layer of scums.

The nature of such scums is shown by the figures here given of the analysis of a sample, which still contains a part of the juice:—

Water	69·72
Sucrose	10·20
Glucose	0·71
Wax	4·12
Albumen	1·80
Ash	8·10
Undetermined	5·35
	100·00

The ash consists of:—

Phosphate of Lime	2·92
Silica	0·37
Iron and Alumina..	1·40
Magnesia	0·22
Sand and Clay	2·82
Undetermined	0·37
	8·10

A knowledge of the action of lime on cane juices of different constitution may be derived from the analyses in the subjoined table, showing that lime precipitates especially albumen, gums, and pectine, and slightly attacks glucose.

CONSTITUENTS.	1st mill.		2nd mill.		3rd mill.	
	Before Defecation.	After Defecation.	Before Defecation.	After Defecation.	Before Defecation.	After Defecation.
Brix	19·2	19·2	19·3	19·7	19·0	19·4
Sucrose	16·49	17·06	16·33	17·06	15·95	16·40
Glucose	1·98	2	1·57	1·58	1·52	1·52
Gums and Pectine	0·125	0·071	0·376	0·120	1·250	0·840
Albumen	0·025	—	0·092	—	0·054	—
Quotient of purity	85·9	87·5	84·4	86·6	84	84·5
Glucose ratio	12·1	11·7	9·6	9·2	9·5	9·3

The estimation of the quantity of lime necessary for clarification is the most important point in the defecation process. When the quantity has been too small, the phosphoric acid and the albumen are imperfectly precipitated, and the insufficiently tempered juice settles slowly and can only with difficulty be clarified. When too much lime is being used the impurities are easily thrown down, and the juice settles quickly. But then another difficulty arises. Lime, like every other alkaline agent, acts, at the high temperature at which the defecation is conducted, on the glucose, forming with it lime salts of organic acids, which are dark coloured and easily decomposed and transformed into acid substances which cause inversion of the sugar. Moreover, these lime salts retard the evaporation and crystallization, and by their viscosity cause considerable loss and annoyance on curing. The greatest care in tempering is therefore advisable, and if there remains a doubt as to whether the exact quantity is being used, it is better to add a little too much rather than too little, for in an insufficiently tempered juice the impurities still remaining cause much trouble during the whole course of manufacture, while an overtempered one may always be neutralized by phosphoric or sulphurous acid.

The amount of lime necessary for tempering is ascertained in different ways. Some people use just so much lime as is necessary for clarified juice to produce a faint alkaline reaction on litmus or tumeric paper; others ascertain in the laboratory how many c.cm. of lime-milk are sufficient to clarify properly one litre of juice at its boiling point, and use the same proportion in the factory. The best method is as follows: First of all, in ordinary working, as much lime is added to the juice as seems appropriate, say two gallons of milk of lime of 15° B. to 500 gallons of juice, and clarification is effected as usual. Then a little juice is taken from the clarifiers, filtered through paper into a test tube with a few drops of sucrate of lime solution added.* If a precipitate is formed it is evident that the juice still contains impurities, and that therefore too little lime has been used. In the next clarifier a somewhat larger quantity of milk of lime is used in tempering, the juice is again tested, and if it again becomes turbid with the sucrate of lime test solution, the quantity of lime is again increased until the filtered juice remains clear after the addition of the test solution. If, on the contrary, the sucrate of lime leaves the juice clear at the first test, either just sufficient or too much lime has been added to the juice. In order to settle this point we gradually diminish the quantity of lime in tempering until the juice becomes under-tempered, when the amount of lime is slightly increased, and this quantity is adopted as the correct one.

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* This solution is made by shaking up lime with a 20% sucrose solution, and filtering. It is much to be preferred to lime water, because a slight precipitation can be better observed with this test solution than with lime water.

This method seems rather complicated, but after some experience and practice the proper quantity is soon found after a few tests. As the chief aim of clarification is to get speedily a juice that settles easily, this way of determining the necessary quantity of lime is the most rational one, and if so much lime is required as to make the juice alkaline after clarification, it may afterwards be neutralized by phosphoric or sulphurous acid. When making high-class sugar a slightly acid reaction of the juice is even an advantage, but in making the so-called "non-chemical" sugar, the juice should be neutral or even a little alkaline, for in these sugars a rather considerable amount of molasses remains between the sugar crystals, which in the case of acidity of the juice gives rise to inversion and deterioration of the sugar.

A great difficulty in the proper conduct of the clarification is the varying composition of the mill juice if canes from different fields are being crushed at the same time. The juice of the canes of each field requires its own special quantity of lime, and if canes of different fields are crushed together, the composition of the mill juice varies every moment, and hence also the quantity of lime necessary for clarification. Of course it is impossible to determine it for each clarification, and hence defecation is a difficult and somewhat uncertain operation.

The mill juice is filtered through copper strainers, and measured in measuring tanks where it is limed, it next passes through a juice-heater, and then enters the clarifiers. In these the defecation takes place, and it may be conducted in two different ways, depending on the manner in which the juice is allowed to settle. In the first method the juice settles in the same vessel in which it has been heated, while in the other the limed and heated juice is run into settling tanks. When adopting the first method the juice is heated to 95° C. in hemispherical copper pans provided with a steam-jacket, into which steam is admitted, which heats the juice as quickly as possible. During this time the now precipitated impurities coagulate, envelop the suspended particles, and form, with the air bubbles escaping from the hot juice, a frothy, dark-coloured layer of scums, underneath which is the clear juice. Only the heavy impurities, such as sand, clay, &c., sink to the bottom and form also a layer of impurities, so that the cane juice is separated into three layers, of which the middle one, consisting of clarified juice, is the greatest. The juice is heated until the layer of scum is just beginning to burst (cracking point); the supply of steam is then immediately shut off, as, if not, the juice would suddenly boil over, and become partly lost. The juice is now allowed to settle, and afterwards let off through a hole at the bottom of the pan, which is fitted with a pipe closed by a three-way cock. By simply turning the plug one is able to draw off successively the heavy impurities, the clean juice, and finally the scum, each of these being conducted into its own gutter. The first and third portions, *i.e.*, the heavy impurities and the scums, are run into the scum tank, while the clean juice is conducted to the evaporators or to the eliminating pans. The three-way cock and the gutters should be placed in an easily accessible and well-lighted position, so as to admit of complete control which is indispensable in this operation.

In the other method, the limed juice, after having passed through a juice-heater, is boiled in iron pans, through which the steam is led by means of coils. As soon as the juice boils a cock is opened at the bottom of the pan, and the hot juice flows into the settling tanks, where the separation of the clear juice from the scum takes place. As the air in this case has been completely driven out by the violent ebullition, the scum does not remain in a frothy mass on the surface, but settles gradually, leaving the juice quite clear.

Instead of these pans, most factories are provided with Fletcher pans; these are cylindrical iron pans carrying a broad gutter. In the pans we find a steam chamber, suspended in such a way that it almost, but not quite, reaches the bottom. The steam chamber is perforated by a number of tubes in which the juice circulates, and thus easily absorbs the heat of the steam introduced in the steam chamber, causing it to boil rapidly.

At first the frothy scum comes to the surface and can be driven into the gutter by long skimmers, whence it flows into the scum tank. When no dark coloured particles are visible at the surface, but only a white mass of steam bubbles, the steam supply is stopped and the juice with the heavy impurities is let off into the settling tanks.

In many places the juice is heated to about 90° in the juice-heater, and then allowed to flow through one or more Fletcher pans, in which it boils rapidly, and next runs into the settling tanks in a continuous stream. In this case no skimming can take place, but as the energetic boiling breaks the layer of scums, this gets mixed up with the heavier deposits and does not interfere with the proper subsiding in the settling tanks. The latter are square iron vats, lined with wood for retaining the heat, and provided with cocks at varying distances from the bottom. The juice settles, the uppermost cock is opened and afterwards the others, so that only the clear juice flows off and goes to the clarified juice tank. Finally a cock at the bottom of the vat is opened, by which the scum flows out and is run into the scum tank.

When the juice has a high density and the quantity of impurities is very small, it often happens that the small amount of scum remains suspended and does not settle in the heavy liquid, but the settling may be promoted in two ways. Some pour cold water from an ordinary watering can upon the hot juice, which dilutes the juice at the surface and causes it to throw down the impurities; and further a downward stream is produced by the cold water, which also imparts a downward direction to the scum.

If the slow subsiding cannot be remedied by a longer stay in the clarifiers, one can adopt the expedient of rendering the scum heavier and more flocculent, which may be done by using a little more lime in tempering and at the same time adding just the quantity of phosphoric acid necessary to again neutralize this excess. The amount of lime remains the same, but a heavy, flocculent precipitate of tribasic phosphate of calcium is produced, which envelops the fine particles of scum, and carries them along with it to the bottom.

In recent years a third method of defecation has come into use, viz., superheat clarification with continuous subsiding after Deming's method. The limed juice is pumped subsequently through three vessels, in which it is heated to over 110° C. under pressure, and afterwards cooled down to about 100° C., so that the juice enters the apparatus at the ordinary temperature, is heated, remains about 45 seconds at a temperature of 110-115°C., and then leaves it at a temperature of 95-100° C. The three vessels consist of strong iron horizontal cylinders, in which tubes of 2 in. diameter are fixed and connected with each other by chambers at the front and back doors of the cylinders in such a way that juice pumped in the tubes flows through them to and fro with great velocity. Two of the vessels are called absorbers; the third, having the largest dimensions, bears the name of digester. The cold juice is introduced in the first absorber outside the tubes, and next through the tubes of the second absorber, around which exhaust steam is admitted. Afterwards the juice flows through the tubes of the digester, and is heated by fresh steam to the temperature of 110-115° C. required in this system of clarification; finally it passes through the tubes of the first absorber on its way to the settling tanks. In this manner it imparts its superfluous heat to the fresh cold juice surrounding the tubes, and heats it to 40-50° C.

Owing to the great velocity with which the juice is forced through the tubes there is no fear of scaling inside; in fact, they remain quite clean even after some months' use. The apparatus requires only now and then a thorough cleaning with hot dilute hydrochloric acid, in consequence of the outside of the tubes in the first absorber becoming dirty with mud from the cane juice.

The hot juice is conveyed into settling tanks, whence it is continuously discharged. These tanks are cylindrical, with a conical bottom, carrying a wide discharge tube provided with a cock. A great cone of sheet iron is suspended in the cylinder; it is open both at the top and at the bottom, and its upper diameter is smaller than the lower. The height of the cone is equal to that of the cylinder, so that their upper edges are at the same level, and the bottom of the cone is just at the same height as the conical under part of the settling tank, the distance between the cone and the tank being at that place but slightly over one inch.

The superheated juice flows into the tank outside of the cone, fills it and is discharged through a wide tube ending high inside the cone. This arrangement occasions a continuous downward current of juice outside, and one in opposite direction inside the cone. The scum has therefore a tendency to sink to the bottom outside, and if it is induced to rise to the surface by the upward current inside the cone, it knocks against its inclined side and sinks again. Care should be taken to always discharge so much subsided scums out of the funnel-shaped bottom that no layer of dirt is formed between the edge of the cone and the cylinder, as in that case great lumps of scum may be carried to the surface and so spoil the clarified subsided juice.

In the case of slowly settling juice the same expedient may be used as in the case of the ordinary clarification, *i.e.*, rendering the precipitate heavier by adding more lime and a corresponding amount of phosphoric acid to the mill juice.

Ordinarily two settling tanks are required; the juice flows first through the smaller, afterwards through the larger one.

This system of clarification divides the juice continuously into clarified juice, ready for evaporation, and into scum, which is conveyed to the scum tank.

Each method of defecation has its advantages and its defects. The advantage of the first method is that the juice is not heated to its boiling point; hence steam is saved, and, further, no danger of inversion or decomposition is to be feared. A drawback, however, of this method is the great number of expensive defecation pans it requires to contain the amount of slowly subsiding juice, if we wish to get a properly clarified cane juice.

The common defecation pans with coils are easy to clean, which is not the case with the pans in which the juice is boiled in tubes of small diameter, unless a sufficient number of these are available, enabling us to dismount one for cleaning, and go on working with the others. The skimming off of the light floating impurities has the disadvantage of keeping the juice for a long time at a high temperature, involving extra expenditure of steam, and it may cause decomposition of a portion of the sugar. This danger, however, is not a very serious one, as special experiments have shown that with skimming, the evaporation of the juice did not exceed 3%, and with defecation, without skimming, only 1·5%, while in both cases the increase in quotient of purity amounts to 0·5%, showing that no perceptible loss of sugar had taken place. Against these disadvantages must be set the gain of at once removing in the skimmings the lighter portions of the scums, leaving therefore only the heavier, and hence more quickly subsiding portion to settle in the settling basins, which saves much time, and so increases the working capacity at this stage.

The advantages of the superheat clarification are saving of steam, labour, and space, whilst the superheated juice subsides better than the simply heated juice. A chemically definable difference between juice clarified by the two ways of heating cannot be detected, as is shown by the tables underneath, where the analysis is submitted of juice from cane of the same field, clarified in the same factory, alternately one day by the usual clarification, and another day by Deming's apparatus.

FIRST DAY.

Variety of cane .. .. Cheribon.

Defecation process .. .. Old defecation.

Liming .. .. 4 to 4½ litres lime 15° Beaumé to 1000 litres juice.

	Brix.	Pol.	Quotient.	Glucose.	Glucose ratio.
First mill juice	16·93	14·97	88·40	1·15	7·7
Last mill juice..	10·58	8·86	83·70	0·70	7·9
Mixed juice..	14·47	12·69	87·70	0·98	7·7
Clarified juice..	14·87	13·21	88·90	0·90	7·4
Syrup	50·59	44·90	88·70	2·90	6·5
Masse-cuite	91·72	81·22	88·50	5·88	7·2
First molasses	79·52	49·20	61·86	14·24	..

SECOND DAY.

Variety of cane .. .. Cheribon.

Defecation process.. .. .. .. Deming's superheat clarification.

Liming .. ..4½ litres to 1000 litres juice.

	Brix.	Pol.	Quotient.	Glucose.	Glucose ratio.
First mill juice	17·35	15·27	88·00	1·24	8·0
Last mill juice	9·02	7·70	85·30	0·60	7·8
Mixed juice..	14·55	12·55	86·20	1·00	8·0
Clarified juice..	14·72	12·67	86·10	0·94	7·4
Syrup	37·98	33·40	87·90	2·58	7·7
Masse-cuite	90·30	80·12	88·70	6·05	7·5
First molasses	80·92	50·60	62·54	16·25	..

THIRD DAY.

Variety of cane .. .. Muntok.
Defecation process .. .. Old defecation.
Liming .. .. .. 4 to 4½ litres to 1000 litres juice.

	Brix.	Pol.	Quotient.	Glucose.	Glucose ratio.
First mill juice	18·70	16·88	90·3	1·24	7·4
Last mill juice	9·30	7·84	84·3	0·57	7·3
Mixed juice..	16·10	14·23	88·4	1·03	7·2
Clarified juice..	16·53	15·00	90·8	0·99	6·6
Syrup	45·72	41·2	90·1	2·56	6·2
Masse-cuite	92·00	82·94	90·2	5·42	6·5
First molasses	79·6	50·8	63·8	14·80	..

FOURTH DAY.

Variety of cane .. .. Muntok.
Defecation process .. Deeming's superheat clarification.
Liming .. .. 4·2 litres to 1000 litres juice.

	Brix.	Pol.	Quotient.	Glucose.	Glucose ratio.
First mill juice	18·71	16·72	89·40	1·53	9·1
Last mill juice	10·70	9·02	84·30	0·84	9·3
Mixed juice	16·92	14·71	87·00	1·37	9·3
Clarified juice..	16·67	14 69	18·10	1·21	8·2
Syrup	40·7	36·40	89·40	3·02	8·3
Masse-cuite	91·4	80·51	88·10	6·63	8·2
First molasses	79·8	48·80	61·03	16·00	..

2. TREATMENT OF THE CLARIFIED JUICE.

In many factories the juice is pumped off after settling, without any further treatment, into the suction-tank of the evaporators, in others it passes through one or another form of juice filter, while yet in others it is once more boiled in eliminating pans of the same shape as has been previously described. This treatment is especially necessary for juice clarified by the first-named method, as in that case a great part of the scums very often accompany the clarified juice owing to want of attention. The juice, after settling, is boiled, skimmed, and if necessary, rendered neutral by phosphoric or sulphurous acid if the juice is too alkaline, or with soda or lime if it is too acid, because, as already mentioned, a neutral or very slightly acid or alkaline juice is the most advantageous.

Juices which have been allowed to settle in special clarifiers do not need elimination, for in this case the juice can be neutralized directly in the defecation pans.

If the juice is too acid a solution of caustic soda or carbonate of soda of 20° Beaumé is used, so much being taken, in the case of "non-chemical sugar," as will result in a slightly alkaline reaction of the juice with sensitised litmus paper. If, on the other hand, the juice is too alkaline or *neutral* and it is intended to make high-class sugar, the juice is rendered faintly acid with a solution of phosphoric acid of 20° Beaumé, or a stream of the vapour of sulphurous acid is conducted into the juice until the proper acid reaction is obtained.

3. TREATMENT OF THE SCUMS.

The scums from the clarifiers or from the settling tanks are run into the scum tanks as already mentioned. Sometimes the scums are allowed to settle once more, and the clear juice is again drawn off, but generally the scums are mixed with lime and steamed to promote filtration. Many factories only possess a single scum tank, into which the scum continually flows from the clarifiers; it is heated and limed from time to time, and pumped off to the filters, but in this way it is impossible to know whether the scum is sufficiently limed or not. It is much better to have two tanks, and use them alternately, so that the first is filled, properly limed, steamed and emptied, while the second is being filled. Instead of this, a mixer can be put in front of the steaming tank in which the scums are limed, and then run into the tank.

If the defecation has been carried on with sufficiently tempered juice at a proper temperature the scums can be filtered without addition of lime; this agent is however a powerful help if owing to circumstances the clarification has been defective.

II. CARBONATATION.

While it is advisable to avoid an excess of lime in defecation, the carbonatation process, on the contrary, requires it. Here the juice is mixed with a large excess of lime, during which operation the temperature should not exceed 60°, and afterwards the excess of lime is removed by a stream of carbonic acid. The action of the lime is here somewhat different from that in defecation; it precipitates albumen and gums, but, in addition, in its concentrated state it also attacks glucose, and transforms it into organic acids. We have already seen, in speaking of the defecation process, that when this action of the lime takes place at the temperature of boiling juice, the lime salts are dark coloured, viscous, and very troublesome, but if the lime acts upon glucose at temperatures below 60°, the lime salts then produced are partially insoluble, and easy to be removed, the remainder being colourless, very soluble and stable bodies, giving no trouble whatever. Moreover the juices become very light in colour, are clear, easily filtered, evaporated, and boiled, as with the great excess of lime more of the gummy matter is thrown down than in simple defecation, as is shown by the following table:—

	Brix.	Sucrose.	Glucose.	Pectine.	Glucose per 100 Sucrose.	Quotient of purity.
Mill juice	18·4	15·72	0·92	0·634	5·9	85·6
Mill juice, clarified by defecation	18·6	15·99	0·95	0·292	5·9	86·1
Mill juice, clarified by carbonatation	16·9	14·65	0·44	0·142	3·0	86·7

As soon as the lime has finished its purifying action, the excess is removed by carbonic acid, which combines with the lime and forms insoluble carbonate of calcium. This saturation may be effected in one or in two operations, and according as this is done the process may be distinguised by the name of single or double carbonatation, the difference being as follows:—

On treating cane juice with an excess of lime at a temperature between 55° and 60°C., besides the already-mentioned pectine, gum, and albumen, a basic lime salt of an organic acid derived from the glucose, probably a basic glucinate of lime, is thrown down. This salt is dark coloured and liable to spontaneous decomposition, but so long as it remains in an alkaline medium at the said temperature it is insoluble, and can be removed by filtration. If therefore the carbonated cane juice is filtered at the time when the great bulk of the lime is already precipitated by the carbonic acid, but the juice is still alkaline, and the temperature does not exceed 60°C., we get a very light coloured juice, and the basic salt passes over into the scums. The juice is afterwards neutralized by carbonic acid, and thus all trace of alkalinity is removed without any particle of the first precipitated lime salt getting again dissolved in the neutral juice. This is done by double carbonatation, but if we saturate the limed juice in one operation, causing the basic glucinate to come into a neutral liquid, it changes into the soluble normal glucinate, which colours the juice again. Double carbonatation therefore is apt to yield more completely clarified juice than the single process, while some other points of difference will be mentioned afterwards.

The difference is also clearly shown be the analyses of the scums obtained by the two operations, of which the figures follow here:—

Constituents.	Filter-press cakes from single Carbonatation.	Filter-press cakes from double Carbonatation. 1st saturation.	2nd saturation.
Sucrose	3·90	10·10	8·10
Glucose	—	0·38	—
Cane fibre	3·08	6·10	0·50
Wax	3·43	2·48	—
Organic acids	1·94	2·12	4·20
Albumen	2·55	2·72	—
Gums	1·11	1·20	—
Total organic substances	16·01	25·10	12·80
Carbonate of calcium	67·94	61·94	85·01
Carbonate of magnesium	1·80	1·21	0·10
Iron oxide and alumina	2·41	4·66	0·51
Phosphoric acid	0·71	0·87	0·12
Silica	8·48	1·85	0·64
Sand and clay	2·48	4·37	—
Undetermined inorganic substances	0·17	—	0·82
Total inorganic substances	83·99	74·90	87·20

The carbonatation takes place in large square iron basins, which sometimes are open, but in most cases are covered with an iron plate provided with a lid, permitting samples of the contents to be taken from time to time, and allowing entrance to the basin for cleaning it. A chimney is also fitted to it to carry off the escaping gases. A coil is further fitted in the carbonating basin, into which steam can be admitted, and a perforated iron coil or cross for the carbonic acid.

The basin is half filled with the heated juice, then the proper quantity of lime is poured in, and the supply of carbonic acid turned on, while care is taken that the temperature shall not exceed 55° to 60° C. As already stated, dark coloured lime salts are produced at a higher temperature, and at a lower temperature the action of the carbonic acid (saturation) proceeds too slowly, causing loss of time and of carbonic acid.

During the saturation the juice froths violently, for which reason the basin is only half filled, and for the same reason the lid should be kept closed. If notwithstanding this the juice still foams over between the lid and the plate, a little oil should be poured on it or the froth should be blown down by a jet of steam.

1.—Single Carbonatation.

The carbonic acid is admitted to the juice until a sample of it only gives a faint pink reaction on phenolphthalein paper, and the supply is then slowly shut off, resulting in the juice being just neutral. It is afterwards heated by the steam coil up to 90° C., and filtered through filter-presses, or if the heating of juice containing such a large quantity of scum should be too difficult, the saturated juice may be run off into settling tanks. The clear juice, which is obtained immediately, is syphoned off, the scum steamed with direct steam, and then filtered. The quantity of lime necessary for this operation is entirely regulated by the running of the filter-presses; the precipitate from the juice is rather viscous, and is very difficult to filter, therefore carbonatation aims at mixing it with so much carbonate of lime, that the mixture can be easily filtered. If the filter presses run badly before the chambers are full of scum, the quantity of lime added to the juice should be increased, and as an excess of lime is perfectly harmless in this process we can safely go so far as to use too much, because the carbonic acid is certain to neutralize it. We may, therefore, go on for a long time with one fixed quantity of lime and not have to put up with the inconvenience met with in the defecation process, occasioned by the difference in quality of the juice of canes from various fields. The quantity of lime required is about one per cent. of the weight of cane, and the amount of glucose diminishes during the process to from 25 to 40 per cent. of the original quantity. In order to avoid the large volume of water added to the juice in the lime cream, which has to be evaporated again, some have attempted to apply the lime unslaked. A practical way of doing this has, however, not yet been found out; unslaked lime in pieces is not to be recommended, because of its causing a rise in temperature, and hence increasing the risk of decomposing the glucose and colouring the juice. Dry slaked lime becomes covered with a layer of precipitated impurities as soon as it is put into the juice, thus preventing its further action.

2.—Double Carbonatation.

Continuous examination of the juice during the saturation shows that at the beginning it remains liquid, but gradually thickens in consequence of the gelatinous precipitate, which does not settle. After the admission of more carbonic acid, there is a point at which the precipitate settles rapidly and leaves a bright coloured, clear, alkaline liquid, with an alkalinity of about 0·05% CaO. With the single carbonatation process this alkalinity is likewise neutralized, with the consequence, already mentioned, that the juice again assumes a darker colour, but with double carbonatation the juice is filtered and the precipitate removed.

For the reason already mentioned, this filtration ought also to be performed at a temperature not exceeding 60°, as with a rise in temperature the coloured salt also becomes dissolved. Great care should be taken to stop this first saturation at the exact point when the precipitate settles well, while the juice is still alkaline; if it is stopped too early the juice does not filter well; and if it is allowed to go on too far, the juice becomes coloured owing to the solution of the normal glucinate of lime.

The filtered alkaline juice is pumped into other saturation tanks, which are also fitted with coils and pipes for steam and carbonic acid, but which may be filled to the brim, as in these the juice no longer froths. A slight quantity of lime is added, and saturation repeated up to neutrality; then the juice is boiled to break up bi-carbonates, and again filtered through filter-presses.

Just as with single carbonatation, in this case also the quantity of lime is regulated by the filter-presses. As the juice is now filtered at a low temperature, and in that case the precipitate from the juice is still more difficult to deal with than at a more elevated one, a still greater quantity of lime is required to obtain good hard filter-press cakes, and hence double carbonatation requires more carbonic acid and also more lime than the single process.

When we see by the slow filtration that the precipitate is too viscous, then the quantity of lime must be increased, and in this case also a maximum may be used, because the excess is in like manner neutralized by the acid. As a rule we go as far as 1½% of the weight of cane, and the amount of glucose falls as low as from 20 to 50% of the quantity originally present. A portion of the acids formed is separated by filtration as a basic lime salt, but the greater part remains in the juice as lactate and saccharinate of lime, causing a large increase in the quantity of lime salts in cane juice by carbonatation. In many cases it is impossible to obtain quite neutral juices by saturation with carbonic acid, as either the lime or the juice contains alkali, which becomes carbonate and thus keeps the juice alkaline after saturation also. In order to prevent this, and also with a view of obtaining a still further decoloration, a third saturation, this time with sulphurous acid, is sometimes used in factories working with the double carbonatation process. To this end the saturated juice is pumped into eliminating pans, and sulphurous acid gas is let in, till the juice is neutral with turmeric paper, and remains so after being boiled, after which it is filtered through a juice filter. Great care is recommended in this operation, for an excess of sulphurous acid is very injurious, as will be shown later on.

ADVANTAGES AND DEFECTS OF THE DIFFERENT METHODS.

The advantages of carbonatation are—

1. The clarification of the juice is more effectual, because the viscous gummy matters are precipitated and a part of the glucose is transformed into harmless combinations.

2. The clarified juice is brighter and more easy to work up.

3. The clarification is effected in one single operation; immediately after saturation the liquid is divided into a clear juice, easy to filter, and a scum which settles well, while with the defecation process we are troubled with slowly settling and badly filtering scums, and a slimy, opalescent juice.

4. Independently of the kind of cane crushed, we can employ a like quantity of lime for a long time at a stretch, because if an excess of lime has been used, the carbonic acid neutralizes it afterwards, while the quantity of lime required to be used in defecation is very variable if canes from two different fields are crushed together, and therefore one is not sure of using it in proper quantity, which is a very important point in this operation.

5. Owing to the carbonated juice being purer, brighter, and more easily worked, the quality of the sugar is better than from a like kind of juice clarified by the defecation process.

Against these advantages must be set certain drawbacks, the chief of which is the greater expense, because more lime is required, and moreover the cost of the lime-kiln and fuel, together with that of the carbonic acid pump and further plant, increases the cost price of the sugar.

Further, the work connected with the lime-kiln requires continuous attention; it often occurs that either the lime is burnt at a too high or a too low temperature, or that the quality of the gas is deficient, and there are other drawbacks that we have not to put up with in the defecation process.

In these times, when almost exclusively so-called "non-chemical" sugar or refining crystals are made, it is not advantageous for most factories to use carbonatation. If, on the contrary, we want to make sugar for direct consumption then everything apt to cause coloration should be avoided, and we must have recourse to the double carbonatation process. This requires much lime and carbonic acid, and thus causes considerable expense, but this is more than compensated for by the higher price which sugar for direct consumption fetches when compared with raw sugar.

III.—OTHER CLARIFYING AGENTS.

Besides lime, certain other agents are occasionally used for the purpose of removing impurities from the juice. The principal of these are:—

1. *Phosphoric Acid.*—This is commercially known either as a solution of the pure acid or as combined with lime in the form of superphosphate or acid phosphate of calcium. It is used for neutralizing an excess of lime, and to this end it is added during the elimination of the defecated or carbonated juice; or it

serves during defecation to cause slowly settling precipitates to sink to the bottom, and therefore is added to the juice during clarification together with an equivalent quantity of lime, when the flocculent precipitate of tribasic phosphate of lime carries the impurities to the bottom. Phosphoric acid may also be used for breaking up lime salts, but for this purpose it is more profitable to use the pure acid than the acid phosphate, and afterwards good care must be taken to neutralize the juice with soda. Ordinarily the phosphoric acid is applied in solution of a density of 20° Beaumé.

2. *Sulphurous Acid.*—Sulphurous acid, which in most cases is prepared by burning sulphur in an iron oven, is much cheaper than phosphoric acid, and hence its use is more widely prevalent in sugar manufacturing than that of the other acid. It has, moreover, the further advantage of also exercising a bleaching action on the cane juice. This latter point should, however, not be too much relied upon, as the action only becomes evident when the juice is acid, and is besides very unstable, the sugar becoming dark after being cured and delivered. Sulphurous acid claims the further advantage of promoting the crystallization of the after products and of diminishing the viscosity of the molasses in consequence of its breaking up lime salts, though the direct scientific proof of this decrease in viscosity has as yet not been adduced.

This agent is applied in various ways in different factories; in some, fumes are pumped or drawn by suction into the raw mill juice, in others, into the defecated but not yet settled juice; others, again, apply it to the clarified juice, which is eliminated with its addition, and finally others treat the syrup with it. Being an inorganic acid, it possesses the property of precipitating the albumen in the mill juice and thus facilitating filtration; it further temporarily bleaches the juice. Applied to the clarified juice it will neutralize too great alkalinity, and precipitate lime salts; in this case it is advisable to use it exclusively in the elimination of already clarified juice, and to stop the supply before the juice has become acid, as when this takes place the tubes of the evaporators become too heavily incrusted. When making white sugar, intended for direct consumption, we ought also to be very cautious with the sulphurous acid, for if the juice is allowed to become acid it is bleached, but if afterwards the molasses are not completely removed from the crystals, which cannot be seen by the eye because of their being colourless, the dark colour comes back on contact with the air, and the sugar assumes a dark tinge which diminishes its value.

Acid sulphite of soda or of lime has a similar action to that of sulphurous acid, and also the advantage of breaking up lime salts without causing injurious acidity.

The greatest drawback of sulphurous acid and its salts is the liability of their becoming oxydized and converted into sulphuric acid, which with the lime constantly present forms gypsum ($CaSO_4$), causing incrustations in the tubes of the evaporators and on the coils of the vacuum pans.

3. *Hydrosulphurous Acid.*—This acid is obtained by the action of zinc or tin powder on sulphurous acid, which is thereby reduced to hydrosulphurous acid (H_2SO_2).

This acid has a much stronger bleaching action than has sulphurous acid, and may render good service in the manufacture of refined sugar.

The inventors advise one to introduce the metallic powder and the sulphurous acid into the syrup. As after the treatment the syrup still contains very finely divided metallic powder, it is absolutely necessary to filter it before being boiled into sugar, because of the poisonous properties of zinc. The cane syrup from juice clarified by the defecation process is, however, still so slimy that it will not pass through filter cloth, which disagreeable property is a serious impediment to the process.

4. *Caustic Soda and Carbonate of Sodium.*—It happens in many cases that cane juice still has an acid reaction, although sufficient lime has been added to precipitate all impurities. It is not advisable to evaporate such acid juices, and therefore they should be neutralized, which may be effected during defecation or afterwards on elimination of the settled juices. Until a few years ago, lime was exclusively used for this neutralization, but as lime salts always cause more trouble during the further operation than soda salts, soda has been adopted for this purpose. For purifying purposes lime is, of course, the indispensable agent.

Some use a solution of caustic soda of 20° Beaumé, but others prefer a solution of Solvay soda of the same concentration. This disadvantage of the carbonate (Solvay Soda) is that it effervesces on coming into very acid juice, but this is counterbalanced by the advantages of being cheaper, more easily handled, not attacking the hands and clothes of the workmen, and not causing any alkaline reaction if by chance it is used in excess, as caustic soda does, but only precipitating a little more lime from the juice, which remains neutral.

5. *Barytes.*—This agent has frequently been recommended as a universal clarifying substance, and though it is true that it precipitates from the juice some products of the decomposition of glucose, forming with them salts of baryta, these combinations are by no means completely insoluble, causing the juice thus treated to contain always a certain amount of poisonous material, so that, as a rule, the use of barytes should be condemned.

6. *Chloride of Aluminium, Chloride of Zinc, Chloride of Calcium, Sulphate of Aluminium, &c.*—All these salts have successively been used in clarification for the purpose of precipitating the scum, but none of them has proved successful, because too much of them is needed to produce any tangible effect, and so they have all gone out of use again.

IV.—Filtration.

In sugar factories we meet with two different kinds of filters, viz., juice filters, for the filtration of juice, and scum filters, in which the juice is separated from the scums. Bone black filters are very seldom used in raw sugar factories, though they are indispensable in making sugar for direct consumption.

Juice Filters.

The simplest form of juice filter consists of a bag made of cloth, into which the juice is poured, the clear juice passes through and the impurities are kept back. Such filters are the "Puvrez" filters, consisting of a cylindrical bag, of which one end is closed and the other tied round a pipe supplying the juice to be filtered, which enters into the bag under a certain pressure. The impurities are kept back, and the filtered juice passes through the cloth and flows into an iron gutter to which the bag is fixed, and so is conveyed to the suction tank of the evaporators. A great inconvenience of this filtration from inside to outside is that the finer impurities also are driven between the pores of the cloth and choke them up, so that the bag does not filter a long time before becoming full of scum, and has to be changed. This has been the reason why filters of this description are now generally abandoned, and other systems have been adopted in which the filtration takes place from outside to inside.

In these systems the filter consists of a square iron vessel on which an iron plate is screwed as a cover. In this vessel are a certain number of chambers lined with cloths, kept apart by perforated plates or metal spirals fitted in the chambers. Each chamber is therefore shut off by cloth at the sides and at the bottom, and the upper edges are pressed tightly together, thus preventing the juice, with which the filter is filled, from entering the chamber before having passed through the cloth and left behind its impurities. Each chamber has a spout for the discharge of the filtered juice, and a large cock at the bottom of the filter enables the workman to empty the whole of the contents when it has to be cleaned. When starting, the chambers are supplied with new or clean cloths, the filter is closed by the cover, the screws are tightened, and the hot juice is admitted at a pressure of three to six feet, avoiding great variations. The juice passes through the cloth, leaving behind the suspended particles, which sink to the bottom of the filter, and do not interfere with the filtration through the cloth. This can therefore be used for a long time, but when it is dirty it is changed for a new cloth, and as soon as the contents of the entire filter have become too muddy because of the impurities deposited, it is emptied by means of the cock at the bottom; the juice is conveyed to the scum tank, the filter is washed and is ready for use again.

In many cases the floating impurities of the juice are so fine that filter cloth is unable to retain them; therefore, bagasse is sometimes used as a filtering material. Bagasse from the second mill is preferred, that from the first being too coarse, and that of the third too much crushed and dusty.

The bagasse is put in a square iron box, covered with a lid which is screwed on it. The juice is introduced below, under a pressure of some 4 or 5 feet, forces its way through the bagasse and leaves the filter by a spout or tube just under the rim of the box. The bagasse is therefore constantly kept covered by hot juice, which prevents it getting sour, but promotes the extraction of gummy matter by the hot alkaline juice. When the bagasse is saturated with scum or dirt, it is transported to the mill, which extracts the juice with which the bagasse is imbibed, thus suppressing all loss of saccharine matter which is incurred in the other system by the washing of the dirty filter cloths. The hot steaming bagasse is, however, a difficult material to deal with, besides which the carrying of clean and dirty bagasse to and from the mill through the whole factory is a rather unæsthetic operation.

Scum Filters.

The oldest form of scum filter is the "Taylor" filter, which is still used in several factories. It consists of a number of long narrow double bags, closed at the lower end, suspended in an iron case furnished with a receiver for the scum. Into the bottom of this receiver are screwed several rows of mouth-pieces, round which the above-mentioned bags are tightly fixed. The receiver being filled with the scum, the latter runs into the bags, which retain the impurities, while the clear juice is filtered off and flows into the lower part of the apparatus, from which it is conducted by a gutter to the suction tank of the evaporators.

The front side of the apparatus is provided with a door so as to allow the bags to be changed. When these are full, and no more juice flows off, they are detached from the mouth-pieces, tied round the top, pressed, emptied, and washed. As the filtration proceeds from the inside outwards the same inconvenience is met with as in the "Puvrez" filters, though not in so great a degree, as the pressure is much less and the scum more compact. The disadvantage, that owing to the great surface of bags exposed to the air the juice cools very rapidly, and hence does not filter so quickly, or even becomes easily acid, can be remedied by blowing a constant jet of exhausted steam into the chamber, which keeps up the temperature, prevents sourness, and increases the capacity by 20 per cent.

In place of these filters most factories now use *filter-presses;* which consist of metal chambers lined with cloth, and screwed tightly one against the other A pump or monte-jus, or air compressor, fills them with the hot scum. The juice passes through the cloth and escapes through suitable channels, while the solid matter remains behind in the form of hard cakes. As every chamber has its own spout, which can be closed by a cock, any chamber can be stopped if the filtered juice should be turbid owing to a hole or leak in the filter cloth.

The scum should enter into the filter-press as hot as possible, having an alkaline reaction and at a pressure of from 1½ to 2 atmospheres, When the chambers are full of scum-cake, as indicated by the fact of no more juice flowing off, the supply of scum is stopped, the cakes are washed with water or steam, the press opened, and the cakes removed. The cloths are changed if they have become too dirty, after which the press is again closed by a screw and is ready for further use.

The washing of the filter-press cakes is only applicable in factories using the carbonatation process, because the scums obtained by defecation are much too slimy to allow their being washed out in the press. The steaming of the scums merely has the effect of driving the superfluous juice from between the particles of the cakee, it does not dilute the juice with which the scum is intermixed.

CHAPTER IV.

CONCENTRATION OF THE JUICE.

Up to the point now reached, all the operations the cane juice has undergone, from the moment it left the mills, have had for their object the removal of the non-saccharine matters. It will, however, always be impossible to totally eliminate these foreign matters, and hence no completely pure solution of sucrose can possibly be obtained. The purpose of the operations next following is therefore to bring over the sugar in a solid state; to separate it in a crystallized form from the impurities which remain dissolved in the mother-liquor or molasses. This object is attained by evaporating the water of the juice, and allowing the sugar to crystallize under such circumstances that the maximum of sugar crystallizes out in the purest state possible, and in such a shape that it can easily be separated with a minimum of loss. As sugar is very liable to decomposition and deterioration when occurring in solution, the first and most necessary consideration is to carry on all operations, from the crushing to the boiling, as rapidly as possible, and without the least delay.

The concentration of the juice is ordinarily effected in two stages, viz., *evaporation*, which concentrates the juice to a syrup containing about 50 per cent. of solid matter, and *boiling*, which concentrates this syrup still further, and transforms it into a crystalline mass, containing only from 6 to 8 per cent. of water. Between these two stages, the syrup is in most cases subjected to a second clarification, the successful application of which is of great importance.

1. EVAPORATION.

Formerly the clarified juice was evaporated in shallow pans, known as the "Copperwall," over an open fire, but this process had the inconvenience of very imperfectly utilizing the effect of the fuel, so that a great deal of the latter was wasted, and it was also impossible to prevent local overheating, which caused a portion of the sugar to become decomposed. As the pans were open, and floating impurities were constantly skimmed off, the mechanical purification was a very good one, but this trifling advantage could not counterbalance the enormous losses of sugar and fuel caused by the evaporation over an open fire.

Later on, the juices were evaporated in concretors, *i.e.*, open pans, heated by steam, which secured a more economical utilization of the fuel, and avoided the risk of overheating, but they too were soon supplanted by the multiple-effet apparatus. In these the juice boils *in vacuo*, and therefore at a lower temperature, at which inversion is practically no longer to be feared, and moreover the employment of two, three, or even four vessels consecutively, allows the heat of the steam to be utilized for evaporation as completely as possible; the vapour from the first vessel passes into the steam drum of the second, that from the second heats the juice in the third, and so on, as will be seen from the following description.

The evaporating vessels most generally in use consist of a large iron cylinder, with a dome-shaped head, fitted with a wide tube, which carries off the vapours. The lower part of the cylinder is divided into three portions, the lowest of which is only very shallow, by two transverse plates pierced with round holes, in which are fitted tubes which bring into communication the upper and the lower portions of the cylinder, called together the juice-chamber. The middle portion is called the steam-drum, and is traversed by the tubes, but does not communicate with them. The steam-drum is provided with a supply pipe for exhausted steam, and in most cases with a smaller one for fresh steam, and also with an escape pipe for the condensed water. The wide tube which carries off the vapours from the juice is so constructed as to prevent the particles of the juice from passing off with the vapours, and ends in the steam-drum of a second similar vessel, and so on, while an air-pump is attached to the pipe carrying off the vapour from the last vessel, which draws them off and condenses them. The steam-drums are also emptied by means of pumps.

In the case of a triple-effet, supposing all the vessels to be filled with juice, the following is what takes place when steam is admitted to the steam-drum of the first vessel:—

The steam, having a temperature of over 100°, causes the juice in the first vessel to boil, and becomes condensed itself. The vapours from the juice enter into the steam-drum of the second vessel and heat the juice contained in the juice-chamber, where it is under a certain vacuum, and therefore boils at a lower temperature than in the first vessel. The vapour formed here is easily capable of heating to boiling point the juice in the third vessel, because this boils in a space which is in immediate communication with the air-pump and the condenser. The vacuum is therefore greatest in the last vessel, and least in the first, and consequently the juice in the last vessel boils at the lowest temperature.

The draining off of the condensed water from the steam-drum of the first vessel is effected by a syphon tube of about 15 feet in height, measuring from the lowest tube-plate, while the water of the second and third vessels is removed by a pump, if it is to be used again for feeding the boiler; in the contrary case the steam-drums are simply connected with the air-pump. The steam-drums are therefore always kept clear both from water and from incondensable gases, and as the vapours from the juice in the preceding vessels are immediately condensed by the cold juice, they cause a vacuum in the juice-chambers of the first and second vessels.

The clarified juice is pumped into a tank, from which it flows into the first vessel by its own weight, or is pumped into it if the first vessel is worked under pressure. It enters underneath into the juice-chamber, where various arrangements are made to facilitate the free mixture of the fresh juice with the juice already present in order to ensure a good circulation. The vessels are connected with one another by means of pipes provided with valve cocks. By the cautious opening of these cocks the juice is sucked from the first vessel into the second, and from there into the third, because of the difference in vacuum of the three vessels; in this way the clarified juice enters into the system, and leaves it with the concentration of syrup. A proper regulation of the cocks permits the supply of juice to equal the evaporation, so that the concentration goes on steadily without changing the position of the valves.

When working with the triple-effet we have to take care to keep only such quantity of juice in the first vessel for the upper tube-plate to be just covered by the juice in full ebullition ; if the hot tubes are not constantly moistened by the spattering juice, overheating is to be feared, and if the vessels are too full we run the risk of losing juice by its passing off with the current of vapour as it leaves the vessel. These rules are also applicable to the other vessels, though with them the danger of overheating is not so great. In case they are insufficiently filled, they should be supplied from the other vessels; in the contrary case, the supply is stopped, but the syrup is only drawn off when it has the required specific gravity.

In order to avoid considerable loss of syrup, it is advisable to have a separator between the last vessel and the air pump. This is usually a cylindrical vessel, provided with perforated diaphragms which slacken the speed of the vapour and compel it to part with the drops of syrup it carries along. The recuperated syrup collects on the bottom and flows back into the last vessel by means of a discharge tube.

If the condensed vapour is to be used for feeding the boilers, good care should be taken to prevent its containing any sugar from juice spattering over, as this has a very noxious effect on the boiler plates; it is therefore necessary to examine the condensed water from time to time, the more so as leaks in the tubes may also lead to the contamination of the condensed water with juice.*

Owing to the concentration of the cane juice, various substances which had been dissolved in the thin juice are separated in an insoluble state; they partly remain in the juice, rendering it turbid, and partly are deposited as a hard crust on the tubes, mostly on those of the last vessel, and interfere with the conduction of heat, and hence with the evaporation. Attempts have been made to prevent this by placing in the tubes wooden staves about $\frac{1}{8}$ inch less in diameter than the latter; these possess the double advantage of diminishing the volume of juice passing along a given heating surface, and of affording by their rough surface a better attachment for the incrustation than the smooth brass tubes. This, however, does not prevent the necessity of the vessels being cleansed from time to time, and this is effected by boiling in them caustic soda (or, if this is not to be had, anhydrous carbonate of soda mixed with half its weight of lime, these two constituents together forming caustic soda in the triple-effet). The boiling is done with open valve and with fresh steam in the steam-drum, and hence at the ordinary atmospheric pressure, else the temperature is not sufficiently elevated; afterwards the caustic soda is let off, the vessel washed with water and a dilute solution of hydrochloric acid boiled in it; then it is again washed with water, when the tubes can be cleaned by scraping. Note should be taken of the fact that by the action of the acid hydrogen will be given off, which forms an explosive mixture with the air, and therefore no workmen should enter the vessels with a light before they have been thoroughly washed out with water or the air has been drawn off by the air pump.

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* This examination can be made by boiling about 50 c.cm. of the condensed water for a few moments with a little hydrochloric acid, neutralizing it afterwards with caustic soda, and heating it again after addition of a little Fehling's solution, in which case a precipitate of red cuprous oxide reveals the presence of sugar. The reaction with an alcoholic α-naphthol solution (10 per cent.), of which 1 c.cm with 3 c.cm. of sulphuric acid and 1 c.cm. of condensed water assumes a blue colouration in case sugar is present, is too sensitive a test, as it detects even trifling traces of sugar which are practically insignificant.

The analysis of scales from the different vessels of a quadruple effet gave these figures.[*]

	1st vessel. Per cent.	2nd vessel. Per cent.	3rd vessel. Per cent.	4th vessel. Per cent.
Phosphate of lime	57·85	56·98	15·02	7·49
Sulphate of lime	2·02	1·92	0·54	1·65
Carbonate of lime	3·25	4·68	19·55	9·93
Silicate of lime	7·86	13·31	0·71	7·02
Oxalate of lime	—	—	11·32	11·27
Iron oxide	2·03	1·53	2·31	2·58
Silica	7·79	7·43	39·26	54·34
Combustible matter	20·37	13·41	11·04	5·08
	101·17	99·26	99·75	99·36

Besides the double, triple, and quadruple-effets already mentioned, horizontal vessels are also used in the system called "Yaryan," mainly based on the same principle. They have this advantage, that the juice flows rapidly through tubes of small diameter, and is therefore concentrated in a few minutes, but to this end the tubes must be kept clean with great care, and this causes so much trouble that the apparatus seems to find no great favour with sugar manufacturers.

2. Clarification of the Syrup.

During the evaporation many matters held in solution by the clarified juice assume an insoluble condition, owing to the higher concentration. Among these we find—besides silica—gypsum, phosphate of lime, and caramelaceous substances produced from sucrose or glucose by local overheating, which causes all clarified juices, even the purest, to become turbid again after concentration. It is very important to remove these impurities, for if they become enclosed in the sugar-crystals, as they form during the boiling process, they impart to them a dark tinge, which cannot be got rid of by washing. It is not feasible to remove these matters by filtration, as in factories employing the defecation processes the syrup contains too much pectine to be filtered; on the contrary, the syrup from juice clarified by carbonatation passes easily through any kind of juice filter. The best method of clarification is by boiling the syrup in eliminating pans after it leaves the triple-effet, and neutralizing it, if necessary, with soda, or, if it is too alkaline, with sulphurous or phosphoric acid, after which it is run off into settling tanks similar to those already described in Chapter III.

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[*] Kohus Archief, 1900, 694.

If the precipitate subsides slowly, a little phosphoric acid, together with some lime or soda, may be used in elimination, but great care must be taken not to use too much of these, as in that case the stratum of precipitate might become too thick.

Sometimes juice, which is neutral after defecation, yields a very acid syrup, but in this case no attempt should be made to remedy the defect by using more lime on tempering, for, however strange it may appear, this is more apt to increase the acidity of the syrup than to diminish it. The only thing that can be done is to neutralize the quantity of juice under operation, and seek immediately for the source of this acidity. In every case where a neutral clarified juice becomes very acid during manufacture, this must be due to some agent, which mostly consists of some fermentative organism or other which attacks sucrose and forms acid from it. As a rule, lime salts favour these fermentations, hence a large use of lime render the conditions of life of these organisms more advantageous, and thus promotes the deterioration. This can therefore be remedied at once by keeping the amount of lime as low as possible, and by great care in cleaning all pipes, tanks, and pumps, and even disinfecting them with a 1% solution of fluoride of ammonia. It is of course still better to prevent such infection by daily washing out the gutters and settling tanks.

With juices, too, containing much glucose, a rapid decrease of alkalinity is observed, which however does not change into sourness as is the case with fermentation.

As soon as the syrup has settled, it is drawn off from the precipitate and conveyed to the suction tank of the vacuum pan, while the precipitate is dealt with in various ways. Some manufacturers mix it with the molasses coming from the centrifugals, and boil them together to second sugars. There could not be any objection to this process if the second boilings were always sure of finding a market, for the fine particles of the precipitate would be got rid of in the crystals of the second sugars, but in many cases the second sugars are again melted in the juice, and thus the impurities, previously eliminated with care, are again returned into the juice. Moreover, the introduction of the returning of molasses into the pan has suppressed the second sugars, so that the mixing of the syrup bottoms with first molasses has become impossible. In other factories the scums of the thick juice are run into the scum-tank of the mill-juice, which proceeding has the drawback of increasing the work of the scum filters, and thus diminishing the capacity at that stage. Further, this scum is very slimy, and the fixed particles are excessively fine, so that they will choke up the meshes of the filter-cloths, and finally these scums represent a highly concentrated sugar solution, which results in the scum-cakes being separated from a rather rich juice, and as even the most solid scum-cakes still contain a quantity of free juice, amounting to about 50%, it is not an economical proceeding when we remember that this is concentrated juice, in which a considerable quantity of sugar becomes lost. The best way is to pump the thick juice scums into the juice in the defecation pans; the syrup becomes mixed with the great volume of mill juice without any visible increase of concentration, and again undergoes all the operations of clarification and settling, while the fine precipitate is likewise taken up by the flocculent scums of the mill juice, subsides with them, and does not give rise to any increase in the quantity of juice to be filtered by the filter presses. Moreover, the higher sugar content of this juice is so trifling, that the loss of sugar in the filter-press cakes is not perceptibly increased.

3.—BOILING.

During the boiling process the concentration of the clarified thick-juice is continued to the point where there is not sufficient water for the sugar to remain dissolved, and it is forced to become partially crystallized. This may be done either by evaporating the saccharine solution at a high temperature to such a degree that the clear concentrated syrup only deposits its sugar on cooling down, or by evaporating it at a not too elevated temperature until the sugar commences already to crystallize in the pan, after which the crystals grow slowly as evaporation is continued, and the entire mass is ultimately transformed into a stiff *magma*, consisting of a large quantity of crystals and only a little molasses, in which state it leaves the pan. The rapidity with which sugar crystallizes out from a solution, depends, all other circumstances remaining the same, on the purity of the solution, *i.e.*, on whether much or little foreign substance is present along with the sugar. When the sugar solution is tolerably pure, crystallization takes place as soon as the concentration has become too great for all the sugar to remain in solution; during the boiling process crystals are already formed in the pan, and so the graining of thick-juice is a somewhat easy operation. When an impure juice, such as molasses, is evaporated, crystallization takes place only very slowly, and no crystals are visible, even when the concentration is much greater than corresponds with the solubility of sucrose. These impure syrups cannot be grained, but are boiled smooth, after which they are allowed to cool down, and after some time sugar crystallizes out, partly because it is less soluble in cold water than in hot, but chiefly because of its undergoing transition from the supersaturated state into the normal state of solubility.

Boiling is in the present day always performed *in vacuo*, for the same reason as already mentioned under the heading "Evaporation," viz., that the high concentration considerably increases the risk of overheating. The syrup or molasses is drawn into the pan, and heated by means of a steam coil, while the vapours are pumped out by an air pump and condensed.

The oldest vacuum pans were made of copper, but owing to the efforts made to obtain as large a capacity as possible, they are now almost exclusively made of iron, and those of copper, provided with a steam-jacket, are the exception. Yet they had some advantages over those of modern construction; firstly, the surface of heated metal was greater by some square feet, owing to the copper steam-jacket; and secondly, the masse-cuite in the pan suffered less from the cooling influence of the atmosphere.

The boiling to grain is based on the evaporation in the pan of a quantity of syrup to such a concentration that it contains much more sugar than it can hold suspended at rest or at a lower temperature. By suddenly lowering the temperature a part of this dissolved sugar is thrown down in the shape of fine crystals, and then the skill of the pan-boiler comes into play in making these grow, by repeatedly drawing syrup into the pan and concentrating it without permitting the formation of fresh fine crystals from the syrup afterwards drawn in. Good care should be taken when graining to form at the outset as great a quantity of crystals (numerically) as should ultimately be present in a full-grown state in the masse-cuite. When making coarse grain, we have to form fewer crystals and to boil more slowly than when we want to make fine grain.

When making sugar of an average size of grain, the procedure is as follows, provided that the purity of the syrup is not too low. By bringing the air-pump into action we commence forming a vacuum in the pan and start the supply of syrup, which is drawn into the pan, and this is continued until one or two coils are covered, into which steam is introduced. With a vacuum of 24 inches, corresponding with a temperature of 140° F., the syrup is evaporated, and so much syrup is gradually supplied that the coils, into which steam is admitted, remain constantly covered so as to prevent the emergence from the syrup of any hot surface on which drops of liquid thrown up could get dried, causing decomposition of the sugar contained therein, and changing it into sticky and dark-coloured products.

The contents of the pan, which at the beginning boiled very briskly, by degrees assume a slower movement corresponding with the increase of concentration, and the evaporation is continued until the pan-boiler can see, judging from the degree of viscosity the spattering syrup marks on the sight-glass, that it is ready for graining. The steam is then lessened and the injection increased, by which operation the temperature of the contents is reduced to about 120° F. The syrup, which was already supersaturated at the higher temperature, can now, at the lower temperature, no longer hold all the sugar, which is deposited in the form of small, bright crystals. After having convinced one's self, by means of two or three samples taken with the proof-stick, that the quantity of crystals does not increase, the supply of juice is slightly turned on and the syrup is drawn carefully into the pan, either in a continuous stream or with intervals. Next more steam is admitted, and we continue drawing syrup into the pan, which gradually becomes full, and as soon as a coil of the worm is covered, steam is turned on in it. These data apply to the production of a medium-sized grain; when making coarse grain it is well to grain "low down," *i.e.*, to have only a small quantity of syrup in the pan when graining, using not too concentrated syrup and keeping the contents of the pan in gentle motion by careful management of the steam and injection apparatus. By this means the particles of sugar are forced to deposit themselves on already existing grain, which is accordingly increased in size, and this growth is further promoted by drawing in large quantities of syrup at lengthened intervals. When making fine grain, the custom is to start graining high up, drawing in repeatedly small quantities of syrup and boiling very rapidly, so as to prevent the crystals from growing too fast; owing to the violent movement, they are thrown against each other and against the walls of the pan.

By constant sampling with the proof-stick, the boiler should take care to avoid allowing the crystals to be suspended in a liquid too viscous to permit their movement, and yet not too thin, in which case there would be a risk of the already formed grain becoming dissolved.

When during the boiling process one of these samples proves to contain very small crystals occurring between the original grains, and imparting a turbid appearance to the mother-liquor, these crystals should be dissolved again. To this end a large quantity of thick juice is drawn into the pan, the injection is diminished, more steam is turned on in order to raise the temperature, which dissolves the fine crystals and also a portion of the large ones, but by causing the temperature to fall again slowly, the latter find opportunity to grow again.

When the pan is full, the supply of syrup is stopped, and the contents concentrated; the exact point at which this concentration should be arrested, *i.e.*, the striking point, has to be found by experience, and is determined by the firmness a sample taken out of the pan by means of a proof-stick acquires when cooled suddenly in a pail of water. In case a very hard grain is required, the temperature should be kept rather high in the pan (about 150° F. is the most favourable temperature), but in all cases the temperature should be lowered at the end of the boiling process, in order to force the water still present in the masse-cuite to part with as much sugar as possible.

As soon as the masse-cuite is ready for striking, the steam is shut off, the air-pump and injector are stopped, and by opening a cock in the pan, air is allowed to pass in, when the discharge valve is opened and the masse-cuite discharged from the pan. When the latter is empty, it is steamed in order to dissolve the particles of sugar still adhering to the walls and coils; the steamings are kept separate, so that those from several operations may be cured together, or they are again mixed with the cane-juice. Sometimes, when the grain is very minute, only half the contents of the pan are discharged; it is then closed and fresh syrup is boiled in it, permitting the crystals to grow again—which process bears the name of "cutting."

When impure thick juice is being worked up, it may be more strongly concentrated on graining than in the case of pure juice, because the crystallization does not take place so quickly, but as a rule cane-juice forms grain very easily, and the artifices employed in the beet-sugar industry to promote crystallization are superfluous here.

The way in which a masse-cuite is boiled is of the greatest importance as regards the extractiom of the sugar present in it; when the crystals have sharp edges and are regularly shaped, without any fine crystals (false grain) being at the same time present in the mother-liquor, the molasses easily part from the crystals on curing, and little or no loss ensues.

On the contrary, if the grain is irregular in shape, or if a considerable quantity of very minute crystals are present, a great deal of the already crystallized sugar passes off along with the molasses on curing, and thus becomes lost as available product. The false grain is mixed up with the molasses, forming a viscous compound, which adheres to the larger crystals, and is only to be removed by copious washing with water. Besides the disadvantage of this false grain becoming dissolved during the operation, the water also dissolves a portion of the large crystals, hence diminishing the yield of first sugar. It is therefore evident that where an inexperienced pan-boiler makes from the same quantity of syrup a masse-cuite which gives a low outcome, a skilled man is able to boil it into a very profitable masse-cuite. Close attention should be paid at this stage of manufacture, and every assistant or chief sugar maker should endeavour to learn the art of boiling perfectly, in order to be able to supervise the native workmen properly.

It is a fact that the quantity of sugar crystallizing from a masse-cuite increases according as the water-content diminishes, though this increase is not proportionate to the increase in concentration. The more a masse-cuite is concentrated, the greater the quantity of sugar that crystallizes, but in practical working certain circumstances prevent the concentration proceeding beyond a certain limit, viz., about 6 to 8 per cent. of water, causing the composition of a first masse-cuite, boiled from average juice, to be:—

Sucrose	81·10
Glucose	6·93
Ash	1·12
Water	8·66
Undetermined	2·19
	100·00

A masse-cuite cut from impure juice may give the following figures:—

Sucrose	74·10
Glucose	11·07
Ash	1·54
Water	9·02
Undetermined	4·27
	100·00

But, though it may appear absurd, the quantity of sugar crystallized does not vary very much in the two cases, provided that the amount of water is fairly the same, as sugar is much more soluble in the amount of water contained in a pure masse-cuite than in that of an impure one, causing the quantity of crystallized sugar to be nearly the same. In the first case, one part of water contains about 2·2 parts of sugar = 19·03 per cent. of the masse-cuite; so that 62·07 per cent. of crystallized sugar is present. In the second case, the water contains no more than 1·5 part of sugar = 13·5 per cent. of the masse-cuite, leaving 60·6 per cent. of crystallized sugar present, or only about 1·5 per cent. less than in the former case.

In any case a masse-cuite always contains, dissolved in the molasses which are removed in curing, some 12 to 18 per cent. of sugar from the original thick-juice, which only comes back in the second boiling, and for this reason it has been attempted to obtain part of this sugar also along with the first runnings.

This may be done by boiling the masse-cuite very close, to such a degree that in ordinary working it would be impossible to get it out of the pan, so that the maximum of sugar crystallizes out. A small quantity (about 5 per cent.) of hot molasses is then drawn in, boiled for a moment with the masse-cuite to obtain thorough admixture, when the latter is discharged, and owing to its greater liquidity is very quickly out of the pan. The temperature of the molasses should be higher than that of the masse-cuite for, firstly, cold molasses do not mix well, and, secondly, a part of the sugar dissolved in the hot water of the masse-cuite would be thrown down in the shape of false grain by the rapid cooling. Now it is evident that in this way no considerable advantage can be obtained. Taking 5 per cent. of molasses, containing about 25 per cent. of water, the increase of water is no more than 1·25 per cent., and where this is found sufficient to liquify the masse-cuite the total amount of extra water evaporated by the higher concentration has also not been more than 1·25 per cent., and as 1 part of water had held 2 parts of sugar in solution, the entire additional quantity of sugar crystallized by this process has been about 2·5 per cent.

Another method is boiling very close to a water-content of about 3 per cent., and then diluting with no less than 30 per cent. of hot molasses of about 90° Brix. This mixture, however, cannot be cooled down in the ordinary way, but requires a special cooling *in movement* as will be mentioned afterwards. This large quantity of molasses is able to liquify even the closest boiled masse-cuite, and will save up to as much as 12 per cent. of sugar, which in the ordinary way of working would have passed over with the second boiling or in the molasses.

The consideration that good circulation and slow cooling can induce sucrose to deposit on already existing crystals, even from the most impure mother-lyes, has given rise to the adoption of the many methods of returning molasses into the vacuum pan.

It is a well known fact that by the usual boiling process the desaccharification of the molasses can be advanced very much in the case of impure boilings, in which the solubility of sucrose is very slight.

A masse-cuite having the following analysis—

Sucrose	74·1
Of which crystallized	61·62
,, dissolved	12·48
Glucose	11·07
Ash	1·54
Moisture	9·02
Quotient of purity	81·44

yielded a green molasses, which after being filtered, showed this analysis:—

Sucrose	32·90
Glucose	28·59
Ash	3·91
Moisture	23·37
Quotient of purity	42·86

Such a low quotient could not be expected when centrifugalling a purer masse-cuite; as with cane sugar molasses, the sucrose is less soluble the more glucose it contains. Hence it results that with the same amount of water in the masse-cuite, more sucrose is crystallized out from a masse-cuite of a low quotient than from one having a high quotient of purity.

If, therefore, by a copious addition of molasses to the first masse-cuite, the syrup still present among the sugar crystals in the pan is reduced to the same purity as finally results when boiling masse-cuite from rather impure juice, the same degree of desaccharification may be obtained.

The purer the syrup is of which the masse-cuite is boiled, the more molasses can be sucked in, and every mill which works with this system should ascertain once for all what proportion of masse-cuite and molasses is the most favourable for every degree of purity.

Suppose that we know by experience that the best desaccharification of the molasses is attained when centrifugalling a mixed masse-cuite of 65 purity, and let the quotient of the syrup be 85, that of the molasses 37.

When x is the volume of first masse-cuite on 100 parts of the capacity of the pan we put down this equation—

$$85\,x \times 37\,(100-x) = 100 \times 65$$

$$\therefore x = 58{\cdot}4$$

It is advisable to calculate this figure for every degree of purity both of the syrup and the molasses, and to enter them into a list. Next the division of the pan should be painted on it so as to enable the pan-boiler to see to what mark he has to fill it with masse-cuite from syrup before starting drawing in molasses in every instance.

The masse-cuite from syrup is highly concentrated to such a degree that no movement is visible through the sight-glasses, next a free quantity of molasses is introduced. As soon as the masse-cuite is sufficiently liquified the molasses supply is diminished and the superfluous water evaporated with exhaust steam, this going on until the pan is full. Finally the molasses supply is stopped, and the contents of the pan are concentrated to 95° Brix.

Before returning the green molasses into the pan, they are heated by steam to the same, or a little higher temperature than that of the already formed masse-cuite in the pan. When heating the molasses, a dark greasy foam arises, which is removed by a large hollow spoon provided with small holes. This heating renders the molasses more dilute and easier to be handled, next it dissolves the fine grains usually prevailing in the green molasses, and this is a great advantage, because if it was introduced thus into the pan it would give rise to a secondary crystallization, which afterwards might cause much trouble in the centrifugals, by its choking up the centrifugal gauze.

The proportion of the quantity of molasses added to the original masse-cuite does not only depend on the respective purities of both, but also on the use one will make of the green molasses.

When the aim is to separate the mixed masse-cuite in sugar and exhausted molasses in one operation, more molasses must be added than when it is necessary to obtain one kind or other of after-products of the same. This point will, however, be elucidated later on.

When mixing molasses with the close boiled masse-cuite it sometimes occurs that a layer of hard masse-cuite remains at the bottom untouched, and as this is the place where samples are drawn with the proof-stick, this can lead to erroneous conclusions with regard to the real state of dilution of the contents of the pan. In order to prevent this and in general with a view to promote circulation and to bring along an ascendant current which prevents incrustation of masse-cuite on the steam coils, and thereby overheating and decomposition, a thin perforated copper coil is fitted at the bottom in the pan. Dry steam of a low pressure is introduced in this coil, and owing to the vacuum existing in the pan it penetrates through the masse-cuite stirring it accordingly without interfering very much with the vacuum. Equally to promote a proper mixture it is advisable to suck in the molasses through a bent tube which passes through the masse-cuite and ends at the bottom. The so much lighter molasses entering under the heavy masse-cuite will rise to the surface and thereby ensure a good mixing.

A third way of promoting circulation is met with in pans where molasses are to be boiled on grain. In these pans the steam is not introduced in coils but in a steam chamber of about the same shape as in a triple-effet, save that the diameter of the tubes is larger, since the material to be boiled there is so much more viscous.

The central tube is provided with a stirrer, which agitates the boiling mass and induces a thorough circulation of the same.

Juices which are very impure, or molasses, cannot be grained just like pure juices, but are boiled smooth. In this process they are concentrated to such a degree that they are saturated at the temperature prevailing in the vacuum pan, and afterwards the sugar that is less soluble in the cold masse-cuite is allowed to crystallize in the crystallization cisterns. For this operation a vacuum is created in the pan, the molasses supply is turned on and molasses are drawn in until the coils are quite covered; steam is then admitted into them and water evaporated, molasses being drawn in according as the quantity of liquid in the pan diminishes, so as to keep the coils constantly covered. From time to time a sample is taken from the pan and drawn between the thumb and finger, forming a thread, which breaks at a certain length. If the thread breaks too soon, the concentration has not been carried far enough; if it does not break at all, it has gone too far. The skill and experience of the pan-boiler must decide how much time may be required in each special case, and what appearance the sample ought to have. In the main, we may say that first molasses may be more highly concentrated than second or third, while the temperature at which molasses are boiled is rather high. When the masse-cuite is sufficiently concentrated, the steam, molasses, and air pumps are shut off, and air is admitted into the pan, which is opened, and the contents run into troughs or wagons placed under the opening.

CHAPTER V.

CURING OF FIRST SUGAR.

The operations next following have for their object the separation of the masse-cuite into crystallized sugar and molasses, and as both these constituents are already present as such, they are only of a mechanical nature. It is evident that the most advantageous way is to effect this separation in such a manner that the maximum of the crystallized sugar is obtained at once in the first product, because if portions of it become mixed up again with the molasses, they can only be got back after much trouble and expense, and not even then entirely in the less valuable after-products. It has been proved that the curing is most easily effected, and with a minimum of loss, when the sugar crystals are regular and well-developed, and the mother-liquor is limpid, fluid, and not muddied by the presence of fine, so-called "false" grain.

All the operations which the cane juice has up to now undergone have co-operated to lead to this end. The mills extracted as much juice as possible from the raw material, clarification removed all matters apt to make the juice turbid, a moderate quantity of lime threw down the pectine and albumen, avoiding the formation of viscous, dark coloured lime-salts, after which filtration rid the juice of all suspended impurities. Concentration *in vacuo* prevented overheating and decomposition of sugar, and, finally, good care was taken during the boiling process to form large regular crystals, free from false grain. Notwithstanding all this, careless working between the time when the masse-cuite leaves the pan and the centrifugalling may nullify all the advantages thus gained. When striking the pan, the water of the hot masse-cuite contains more sugar than it can hold after it has been cooled down. In impure masse-cuites this amount is greater than in pure ones, owing to the slow crystallization of sugar from impure liquids, so that all the sugar capable of crystallization has not yet assumed that state in the pan. Under the circumstances prevailing in the crystallizing tanks, in cases where the masse-cuite is very hard and no circulation exists, the sugar afterwards crystallizing out will assume the form of false grain. With pure masse-cuites, in which the quantity of this is trifling, the influence of the false grain is not perceptible, but from impure masse-cuites, especially when they have been boiled at a high temperature, a great deal of sugar will crystallize out afterwards, and even if the boiling is conducted as efficiently as possible, will cause the cooled masse-cuite to contain so much false grain that trouble and loss will arise on curing them.

This is especially the case with such masse-cuites as are boiled very close and afterwards diluted with a large quantity of hot molasses; if these should be cooled down without certain precautions, a mass would result that practically could not be divided into crystals and molasses. Pure masse-cuites can safely be cooled down in the crystallizers, and then yield the maximum outcome, but very impure ones should either be centrifugalled hot from the pan (in which case the sugar crystallizing afterwards cannot interfere with the centrifugalling), or they should be cooled in movement, which operation is indispensable with masse-cuites mixed with molasses.

We have already seen that in the pan the sugar crystals are in constant movement, and come successively in contact with all parts of the liquid from which the sugar is crystallizing out; as a consequence, the crystals grow in size by the sugar depositing itself on them in place of forming new crystals. If this movement is also continued during the cooling down of the masse-cuite, and that cooling takes place slowly and regularly, the sugar afterwards crystallizing out likewise deposits itself on already existing crystals, and does not form false grain; and at the conclusion of the operation even the most impure masse-cuite consists of a mixture of regular, well-formed grains and a limpid molasses not adherent to the crystals. This operation is called *crystallization in motion*, and in combination with the dilution of close-boiled masse-cuites with a large volume of hot concentrated molasses, it enables us to get the maximum amount of sugar from a masse-cuite, because, firstly, much water having been evaporated, therefore the maximum of sugar crystallizes; and, secondly, the systematic cooling causes the crystals to assume such a form that they can be obtained on centrifugalling without appreciable loss.

The apparatus for crystallization in movement may be divided into two groups, viz., the open and the closed. Both of these consist of cylindrical vessels, sometimes provided with a "jacket," into which hot or cold water can be introduced, but having in all cases a shaft with dashers arranged in spiral form, which by revolving keeps the contents in regular and gentle motion.

The open vessels are quite uncovered, and the masse-cuite runs into them through an open trough, while on the contrary the closed vessels have an air-tight connection with the discharge-pipe of the pan and with the mixer placed above the centrifugal; besides this, they can be worked under vacuum, and an air-compressor is fitted to them to bring in compressed air. When the highly concentrated masse-cuite is diluted with from 30 to 50 per cent. of its volume of hot molasses of about 90° Brix., steam is turned off from the pan, the air-cock is opened and also the discharge valve, and air is then pumped out from the vessel; consequently the diluted masse-cuite is drawn into it with great rapidity, when the pan is again ready for immediate use. The opening is now closed and the masse-cuite is slowly cooled in constant movement, after which compressed air is admitted to the vessel and the discharge-vent opened, causing the cold masse-cuite to pass out into the mixer of the centrifugal. In the open systems, the similarly prepared masse-cuite runs through an open gutter into the vessel, is stirred, and afterwards let off by a kind of sluice into a suction-tank, from which it is conveyed to the centrifugal by means of a chain-pump or an elevator. Before the masse-cuite is run in, the apparatus should be heated in order to prevent the hot masse-cuite from depositing minute grain on coming in contact with the cold plates. The shaft should already be in motion on the entrance of the masse-cuite, causing the latter to gradually assume a revolving movement, so that there is no need for starting the movement when the vessel is already full, which might involve risk of breakage. During the stirring and cooling, the masse-cuite becomes harder and harder, and frequently more hot molasses have to be added in order to prevent the breaking of the dashers. After some time, water is introduced into the jacket in such apparatus as are furnished with one. In those which are not, the mass has to cool down by contact with the air—too rapid cooling and too short time of stirring should equally be avoided. When cooling too quickly, the sugar crystallizing out has no opportunity of attaching itself to the old grain, and will therefore form false grain between the large crystals; while if we do not wait till the mixture is sufficiently cold, too much sugar that is still capable of crystallizing is carried off in the molasses in a state of solution, and so the full effect of the operation is not obtained. The most profitable time for stirring, in the case of vessels holding 2,000 gallons, is from 15 to 16 hours.

The differences between using open and closed vessels are as follows:—

The systems with closed vessels have the advantage of allowing the manufacturer to place them (within certain limits) where he likes; by means of the vacuum and the compressed air, the masse-cuite can be conveyed mechanically for some distance and raised a certain height without risk of bruising the crystals. They have, however, the disadvantage of there being a great difficulty in getting a good sample from the interior of the vessel, if it be desired to stir the masse-cuite *in vacuo*. If not, the manhole is simply opened during stirring, and it is only closed when the masse-cuite has to be discharged from the vessel. The closed vessels are therefore under the same conditions as the open ones, and the operation can be surveyed from beginning to end; the mixing of the masse-cuite with the molasses, the heating and cooling, formation or re-dissolving of false grain, &c. The open vessels have the disadvantage that their position is restricted to the close vicinity of the vacuum pans and centrifugals. If the masse-cuite cannot run immediately into the vessels and from those into the suction-tank of the centrifugals, it is necessary to have expensive machinery to convey it from one place to another, which is not only costly as regards the price, but also because a masse-cuite pump or an elevator crushes a great deal of grain, which impedes the curing, and the crushed grain finally becomes lost as first product.

The advantages of crystallization in movement are most obvious in the case of impure masse-cuites, in its bringing over the after-crystallizing sugar also, in a form most available for centrifugalling. For the same reason a large percentage of impure molasses can safely be added to a pure masse-cuite, because even if a portion of the sugar crystals are thereby dissolved, it crystallizes again in a good form by being cooled down in movement. The following table supplies a good illustration of the fact that crystallization in movement does not affect the *quantity* of sugar crystallized out, but only the form in which it crystallizes. Here the analyses of four impure masse-cuites of almost similar composition are given, with the analyses of the molasses existing amongst the crystals, the amounts of crystallized sugar, and of sugar obtained on centrifugalling. Three of them were cooled down at rest and one in movement.

COOLED.	MASSE-CUITE.					MOLASSES DRAINED OUT.					Sugar crystallized.	Amount of crystals obtained on curing.	Loss of crystals on curing per 100 of sugar.
	Sucrose.	Glucose.	Ash.	Water.	Quotient of purity.	Sucrose.	Glucose.	Ash.	Water.	Quotient of purity.			
At rest	74·1	11·07	1·54	9·02	81·44	32·9	26·59	3·91	23·37	42·86	61·62	51·51	16·40
„ „	78·9	8·99	1·16	7·76	85·32	33·7	28·12	3·65	24·50	44·63	68·22	58·61	13·79
„ „	79·0	8·47	1·15	7·82	85·72	32·9	27·52	3·72	26 12	44·67	69·09	55·28	19·88
In movement	77·0	9·62	2·51	7·49	83·45	35·3	26·54	6·70	22·94	46·40	64·	64·	

From these figures it results that the quantity of sugar crystallized did not differ much in all four cases, neither did the chemical analysis of the masse-cuite and of the molasses drained off show any considerable difference, but there are marked differences in the quantity of sugar obtained on curing. While all the sugar crystallized out in the masse-cuite cooled in movement could be obtained on curing. in the other cases, where the after crystallization had taken place at rest, so much false grain had been formed that no less than 13 to 20 per cent. of the crystallized sugar got dissolved again. This table therefore shows clearly the great influence of the shape of the crystals on the yield obtained, and how important it is to pay close attention to the boiling of first sugar, where by want of care more loss can be suffered than at any other stage of the manufacture. Apart from the important advantage of improving the shape of the crystals, crystallization in movement has the further advantage of being a cleanly operation and free from mechanical losses.

The question as to which is best, curing the mixed masse-cuites warm or cold, has been a matter of much discussion; and if the latter, whether cooling in movement is necessary or not.

Generally speaking, one can say that when green molasses are desired, which still yield after-products, no cooling is necessary, but in the contrary case cooling is indispensable if the aim is to separate the masse-cuite in sugar and exhausted molasses. In the first case the vessels serve merely as wash-tanks for the centrifugals, and could just as well be replaced by a gutter provided with an Archimedean screw which carries the hot masse-cuite to the masse-cuite pump.

In the vessels for crystallization in movement but little sucrose crystallizes out from the molasses present in the masse-cuite during the first hours, and the quotient of purity of this molasses does not then decrease much as is shown by the table below. During the cooling process a little masse-cuite was taken from the vessel from time to time, then the molasses was allowed to drain off through a funnel of centrifugal gauze, after which this molasses was analyzed in the usual way.

	Brix.	Pol.	Quotient.
Syrup..	45·48	40·0	87·3
Molasses	—	—	41·0
Mixed masse-cuite	94·58	67·2	71·5

Sample taken.	Temperature.	Brix.	Pol.	Quotient.
During strike	64·5	91·43	39·4	43·09
After 1 hour	64·5	91·43	39·4	43·09
,, 3 hours	63	90·91	39·0	42·9
,, 4 ,,	63	91·06	38·8	42·69
,, 5 ,,	62	91·06	38·5	42·28
,, 7 ,,	61·5	90·96	37·9	41·66
,, 8 ,,	61	91·20	37·8	41·44
,, 9 ,,	60	91·20	37·8	41·44
,, 10 ,,	59	91·16	37·6	41·24
,, 11 ,,	58	90·96	37·6	41·34
,, 12 ,,	58	91·30	37·5	41·10
,, 13 ,,	57	91·24	37·5	41·10
,, 14 ,,	56	90·66	37·4	41·25
,, 15 ,,	56	91·30	37·3	40·85

When stirring for a longer time without cooling by water a larger desaccharification was obtained as is shown here. The analysis showed Brix. 82·36, Pol. 48·6, Quot. 59. The masse-cuite was concentrated to 91·32 Brix., struck, and stirred during 36 hours.

Sample taken.	Temperature.	Brix.	Pol.	Quotient.
During strike	69	87·76	43·0	49·00
After 2 hours	67·5	87·60	41·6	47·49
,, 4 ,,	66	87·30	41·0	46·97
,, 6 ,,	64	87·96	40·2	45·00
,, 8 ,,	62·5	87·62	39·9	45·50
,, 12 ,,	60	87·62	38·8	44·28
,, 16 ,,	57	87·62	38·2	43·60
,, 20 ,,	54·5	86·90	37·2	42·80
,, 24 ,,	52	87·76	37·0	42·17
,, 36 ,,	51·5	87·76	36·6	41·70
Centrifugalled molasses	—	83·56	36·4	43·58

The difference in purity between the molasses prevailing in the masse-cuite and in those drained off in curing, is due to the fact that a little water was used for covering the sugar, which dissolved a little of it and raised the purity of the molasses.

It is obvious that the process of making first sugar and molasses in one operation requires a very large cooling capacity, but a very ingenious device has been invented to restrict this considerably. This consists herein that usually so much molasses is added to the masse-cuite that on cooling down to 60 or 61° C. the purity of the molasses is as low as 40-45. Once or twice a day, dependent on the quantity of molasses on hand, molasses is added to a carefully prepared masse-cuite, which occupies a certain volume, ascertained by experience, of the vacuum pan. The pan is gradually filled with the molasses, concentrated to 95° and struck in the mixers where it is cooled down carefully and constantly kept in motion, until the temperature has fallen to 40° C. and the sugar allowed to crystallize out, leaving an exhausted molasses, which is drained off in the centrifugals and removed from the further course of manufacture.

The question whether it is necessary or useful to return molasses into the first masse-cuite is entirely dominated by the class of sugar which is to be made. When making white sugar in which the faintest yellow tinge is a disadvantage, only pure masse-cuite should be boiled without any addition of molasses. When refining-crystals are made a returning of molasses in order to be able to evaporate the last particles of water from the original masse-cuite will be quite correct. If one still wishes to make an after-product from the molasses no cooling is necessary; cooling on the contrary is indispensable when total separation of commercial sugar and exhausted molasses is aimed at.

The separation of crystals and molasses (properly speaking) is effected in centrifugals; these are flat, cylindrical drums, with perforated walls, provided with a bottom but open at the top, which are made to revolve with great velocity. The masse-cuite is poured into these and is flung by the centrifugal force against the perforated walls, which keep back the crystals, but allow the molasses to pass through. In case the masse-cuite contains false grain, this either passes through the holes along with the molasses and becomes lost for the time, or, what is still worse, gets mixed up with the molasses, forming a sticky mass which chokes the holes in the gauze of the centrifugal and thus prevents the further draining off of the molasses. Not until this mass is again dissolved by steam or water is the way cleared, but by such application of solvents a quantity of the large crystals are likewise dissolved and pass over into the molasses.

Before putting the masse-cuite into the centrifugals, it should be prepared for the operation, as the hard mass is not fit for centrifugalling without preliminary treatment. Masse-cuite cooled in any apparatus for crystallization in movement is ready for curing, but a masse-cuite cooled in the ordinary way must first be broken up into loose crystals in a pug mill, where it is mixed with molasses and reduced to a homogeneous mass—thus obviating the risk of charging the centrifugals irregularly.

When making so-called "non-chemical" sugar, it is sufficient to centrifugal until no more molasses flow off, and then a thin layer of molasses remains adhering to the crystals and imparting to them a brown colour. If, however, high-class sugar has to be made, this layer has also to be removed, which is done by pouring water on the sugar in the centrifugal; the water dilutes the molasses and causes them to be flung through the perforated walls—which operation is called "covering," or washing. This ought to be performed very cautiously in order to prevent too much sugar being dissolved at the same time. To this end various apparatus have been devised, intended to throw the water in a fine spray over the sugar in the drum, and so to moisten a large surface with a small quantity of water, or a nearly saturated solution made of less valuable sugar is used for covering, which, while it removes the molasses, cannot dissolve any crystallized sugar. Finally, steam is used for covering, or a jet of steam which carries air along with it; the steam becomes condensed on the crystals, forming water, which dissolves the thin layer of molasses and is drained off along with this.

It sometimes happens that the molasses present in the masse-cuite are so sticky that they do not permeate the crystalline crust, but remain on the inside of it in the form of a black ring, which cannot be got rid of by washing ; the only thing that can then be done is to stop the centrifugal after it has run for a certain time, and mix the sugar with the layer of tough molasses by stirring, and then centrifugal again.

When the adhering molasses have a very low quotient so that they may be removed as exhausted, and though one would make a high-class sugar, one is compelled to use a great deal of water for covering. This dilutes some sugar and would increase the purity of the molasses if it were allowed to flow into the same receptacle as these. Many expedients have been invented to prevent this by separating the green molasses from the covering water, which permits the possibility of a free use of the latter without fear of losing too much sugar.

The simplest way of performing this is to put two gutters before the centrifugals, one for the poor and one for the rich runnings. A lid moveable on a pin receives the molasses from the centrifugal and, by simply inclining it to one side or the other, discharges them into that gutter where it belongs. This is, however, not quite sufficient as the viscid poor molasses have not yet entirely left the outer drum when covering has already started so that a partial mixing of the two in the outer drum cannot be avoided. Another method is an arrangement in the outer case of the centrifugal, which separates the two runnings; this necessitates the centrifugals being able to rotate in two directions which may be achieve by an improvement in their driving-gear.

A third method is the curing in two sets of centrifugals. In the first set the poor molasses are drained off, next the raw sugar is centrifugalled in the second set after having passed a pug mill, where it becomes mixed with the rich runnings. The runnings from this second set are partially used for mixing the raw sugar, while the remainder is carried back into the juice. It is not advisable to bring it back into the syrup because its density is much higher and it might cause trouble to the pan-boiler when he does not work with syrup of a uniform density.

After curing, sugar in most cases requires to be dried. Formerly sugar was dried in the sun on a plastered floor, but owing to this operation being dependent on the weather and rather expensive, it has been generally abandoned, and the sugar is now dried in large revolving iron cylinders, in which are fitted steam coils, or through which a current of hot air is drawn by a suction pump that carries off the vapours.

Finally, the dry Java sugar is packed in bamboo baskets lined with palm-leaf mats, containing from 6 to 7 cwt., and is then ready for sale.

CHAPTER VI.

AFTER-PRODUCTS.

The molasses draining off from the centrifugals sometimes still contain a considerable quantity of sugar, a certain portion of which can be obtained by repeated evaporation, cooling and centrifugalling. The purer the masse-cuites, the greater will be the quantity of this sugar, as a masse-cuite with much glucose contains less dissolved sugar than one having the same water content with but little glucose. Moreover, a molasses containing much false grain, or one centrifugalled off from high-class sugar which required much water for "covering," is much richer in sugar than molasses centrifugalled from non-chemical sugar or originating from masse-cuites that are treated by one or another method of crystallization in movement. It is therefore not possible to give exact figures for the composition of such first molasses, as all the circumstances mentioned may have exercised an influence on it.

When considering molasses only as the mother-liquor from which has been removed all sugar that can crystallize under the given conditions, and which, therefore, only contains such quantity of sugar as it can hold dissolved in its contained water, or, in short, when considering molasses having the same constitution as it had when present among the crystals in a completely cooled masse-cuite, we notice a certain regularity in the quantity of sugar held in solution.

At the temperature of 85° F., usually prevailing in the tropics, one part of water is able to dissolve 2·158 parts of sugar, and if this solubility were not changed by other constituents of the molasses, a molasses containing 25 per cent. of water would show a polarization of 53·92 per cent. Now the constituents, other than sucrose, which occur in cane-sugar molasses generally possess the property of diminishing the solubility of sugar, contrary to those found in beet-sugar molasses, in which the solubility of sucrose is usually greater than corresponds with the water content. This property is not to be ascribed to glucose alone, for it has been proved by experiment that even large quantities of glucose do not interfere with the solubility of sucrose in water. All the remaining constituents, viz., water, salts of organic and inorganic acids, pectine, gums, albumen, caramel, &c., are equally found in both kinds of molasses, and cannot diminish the solubility here while in beet-sugar molasses they are even considered to increase it. After minute researches, it is established that the diminished solubility of sugar is occasioned by the simultaneous presence of glucose and salts, especially those of organic acids, and this in such a manner that the lowest solubility corresponds with the highest quotient between glucose and salts. There is however a limit to this, for if the quantity of salts is so trifling that it is almost nil, their action is too insignificant to be able to exercise any influence. In case the quantity of salts is so great that it is preponderant as regards the glucose, these constituents increase the solubility of the sugar, just as is the case with beet-sugar molasses, which likewise contain a large quantity of salts, but little or no glucose.

A series of cane molasses of different origin, all representing fully crystallized mother-liquors, will show this regularity tolerably clearly.

Absolutely strict regularity, however, does not exist, and it could not be expected, where, as in the table, the glucose has been divided by the sum of all the ash constituents, as each of these constituents is, of course, sure to have had its particular share in the decrease of the solubility. Notwithstanding this, a steady decline in the figure representing the solubility, accompanying a rise of the quotient between glucose and ash, is perceptible.

The consequence is that where in cane juices the amount of inorganic constituents does not vary very much, while that of the glucose does, the crystallization of sugar is greatest in those masse-cuites containing the largest amount of glucose, causing the crystallization of sugar to be comparatively large in impure masse-cuites. This point at the same time affords an explanation of the fact that first masse-cuites, containing very varying amounts of sugar with a like amount of water, yet contain pretty nearly the same percentage of crystallized sugar. In those containing most sugar, hence the purest, with a like amount of water, the solubility is greater, and hence more sugar has remained in solution. This consideration must not, however, lead to the conclusion that we had better leave the juices as impure as possible, in order to ensure a complete exhaustion of the molasses, for it should not be forgotten that the great quantity of non-saccharine matters also increases the total quantity of molasses, so that though with impure juices relatively little sugar is dissolved in a given quantity of molasses, the absolute quantity of sugar lost in the much larger amount of molasses (due to the impurities) is so much the greater.

In considering the table, it must be borne in mind that in practical working the molasses contain more sucrose, as it is impossible in daily working to free them so completely from minute grain as has been done here in the laboratory. especially in the case of first molasses coming from masse-cuites, the sugar of which required much washing, which are generally enriched by the water used in that operation.

As the first molasses are generally diluted in the factory with water or the condensed steam used for washing, they are in a very favourable condition for fermentation, and should therefore be concentrated as quickly as possible. Now molasses contain, as is self-evident, all the impurities from the masse-cuite in a much more concentrated state than they were in the juice, sometimes even to such a degree that a fresh clarification may become necessary. Strictly speaking, we should never omit to clarify all molasses again before boiling them.

To this end they are run into an eliminating pan, and heated by means of a steam jet. A greasy tough froth now appears on the surface, which is skimmed off, and contains all the floating and suspended impurities of the molasses. At the same time the hot steam, in combination with the resulting dilution, dissolves the fine crystals which had passed through the interstices of the wire gauze in the centrifugal, and were suspended in the molasses.

No.	Sucrose.	Glucose.	Ash.	Water.	Glucose: Ash.	Sucrose on 100 parts of Water.
1	47·90	17·44	7·0	16·45	2·49	291·1
2	47·80	14·53	6·66	17·12	2·18	279·2
3	43·70	15·80	6·50	17·10	2·43	255·6
4	59·20	7·29	6·07	25·12	2·31	235·6
5	58·70	9·97	3·82	25·71	2·61	227·8
6	50·20	15·14	4·35	25·31	3·48	198·3
7	35·30	27·60	8·08	19·10	3·42	184·5
8	49·00	16·52	2·52	27·77	6·56	180·0
9	36·90	26·30	4·97	23·2	5·29	159·0
10	33·80	28·20	6·88	22·98	4·10	151·5
11	43·10	20·87	3·39	28·45	6·16	150·8
12	34·10	23·	7·8	22·90	2·95	149·0
13	42·90	19·93	3·	28·93	6·64	148·6
14	34·05	28·12	3·65	24·50	7·70	145·7
15	34·05	27·78	4·16	25·38	6·67	134·2
16	23·94	40·	5·30	18·0	4·31	133·0
17	30·90	27·74	6·37	24·14	4·31	128·0
18	32·19	30·30	3·77	26·22	8·03	126·6
19	32·90	27·53	3·72	26·12	7·40	126·0
20	29·60	32·40	5·79	23·80	5·6	152·2
21	30·34	28·57	4·02	25·01	7·11	121·3
22	30·69	31·73	3·65	25·77	4·17	119·1
23	28·50	32·81	4·52	24·06	7·26	118·4
24	28·12	31·82	4·64	24·44	6·86	115·1
25	32·40	23·	5·20	28·6	4·42	113·3
26	27·01	37·46	3·09	25·58	12·12	105·6
27	27·20	30·	5·	28·	6·	97·2
28	22·42	34·57	3·30	26·07	10·46	86·0

It is very important that the molasses should come into the pan clear, and free from suspended particles of sugar, for if they enter the pan in a turbid state, the crystals settle on the coils of the steam pipe and are the cause of many products of decomposition, due to over–heating. Moreover, during the elimination a good opportunity is afforded for breaking up any excess of lime-salts by sulphurous or phosphoric acid, or for neutralizing too acid molasses with lime, or better still, with soda. The best way is to heat the molasses as they are, without any addition, with their own acid reaction, skim off the floating impurities, and if necessary neutralize them afterwards.

Pure first molasses, such as are obtained when making white sugar, can be boiled on grain and cooled in motion. The chief requirement is that their purity be sufficiently high as to allow their being boiled on grain, which can only be done with very superior runnings.

These first molasses, with a quotient of from 65 to 67, are grained in a special vacuum pan, concentrated, and struck in an apparatus for crystallization in movement, which is caused to revolve a few times a day during a few hours. After some two or three days the cooled second-boilings masse-cuite is centrifugalled.

While under the old and still much used systems, the molasses require repeated boiling, cooling, and curing before they could be fully exhausted, this result is now obtainable in one operation, as is shown by the following tables, in which again the figures refer to the molasses occurring among the sugar crystals in the masse-cuites.

Analysis of the masse-cuite: Brix. 92·6, Pol. 59·2, Gluc. 12·25, Quot. 63·93.

Sample taken.	Temperature.	Brix.	Pol.	Gluc.	Quotient.
On striking	72	91·3	45·0	16·12	49·28
After 24 hours	60	89·7	36·8	18·31	41·02
,, 48 ,,	51	88·9	34·0	19·22	38·24
,, 72 ,,	44	88·6	32·8	20·83	37·02
,, 96 ,,	39·5	88·3	31·2	21·27	35·33
Centrifugalled molasses.	—	87·4	34·0	19·84	38·90

The less pure molasses are drawn into the pan and boiled smooth, the first molasses rather close, the second (if necessary) more open.

Contrary to what is the case with the boiling of grain, where the object is to form as much crystal as possible in the pan, and hence care is taken to boil at a low temperature at the end, molasses are boiled at a high temperature in order to allow the masse-cuite to become highly concentrated before the sugar finds an opportunity for crystallizing. While the final temperature of a first sugar masse-cuite very seldom exceeds 135° F., a first molasses masse-cuite is generally discharged at a temperature of 155° F.

These high temperatures have the disadvantage, owing to the steadily increasing percentage of glucose, of readily forming decomposing bodies, especially from the lævulose present, so that it is not desirable to proceed too far in this direction.

Fixed rules for the boiling of molasses cannot be laid down, chiefly because the composition of first, second, or third molasses varies irregularly, and under certain circumstances a third molasses may be purer and richer than a first one.

This may be seen from the preceding table, where Nos. 2, 4, 5, 6, 8, 11, 13, and 19 are centrifugalled from first products; Nos. 1, 15, 18, and 21 from first molasses masse-cuites; Nos. 17, 22, 26, and 28 from second; Nos. 10 and 24 from third molasses; while Nos. 3, 7, 9, 12, 16, 20, 23, 25, and 27 represent completely worked out final molasses. We see that the molasses Nos. 14 and 19, originating from first product, were yet poorer than many that had already been boiled several times, and even than some final molasses, so that it is evident that the way in which the different molasses are to be boiled should be ascertained by experiment in each individual factory.

The boiled molasses are discharged into crystallization tanks, where they are allowed to cool down, and where the sugar that can now no longer be retained in solution finds opportunity to crystallize. The rapidity of this crystallization and the size of the crystals depend, in addition to the rapidity with which the cooling goes on, on the nature of the liquid in which they are formed. Pure liquid molasses deposit much more quickly a larger grain than impure and viscous ones, where the cooling time is the same; therefore first molasses masse-cuites are generally allowed to cool down for a week, second ones a fortnight, and so on, before being centrifugalled. From what has already besn said it results, however, that these limits need not be scrupulously adhered to, and an impure first-molasses masse-cuite may be allowed more than a week to crystallize, if this can be done without interfering with the regular operations, though the dimensions of the crystallizers have also a good deal to do with the matter. The cooling and crystallization are much more quickly effected in small iron cisterns, standing quite free, than in large brick ones, built up from the ground.

As a rule the cisterns should be of sufficient size for the contents of one pan to fill them completely and not so large as to be only filled after three or four consecutive operations, for in this case the crystallization is disturbed every time a fresh supply is run in, and hence the grain formed is irregular.

Although it is not possible to give constant figures for the constitution of molasses masse-cuites, the analysis of a first, second, and third molasses, both before and after boiling, originating from the same factory, may follow here, as they admit to some extent of mutual comparison.

	Brix.	Sucrose.	Glucose.	Ash.	Water.
1st molasses before boiling ..	82·70	49·6	12·3	5·04	20·55
2nd ,, ,, ,, ...	81·10	46·0	13·4	5·20	23·27
3rd ,, ,, ,, ...	83·20	44·8	17·5	6·60	20·28
1st ,, after ,, ...	89·70	53·6	12·7	5·45	16·8
2nd ,, ,, ,, ...	88·40	49·6	16·0	5·30	18·3
3rd ,, ,, ,, ...	90·70	48·5	17·9	6·87	14·10

In boiling molasses no more than five or six per oent. of water is evaporated, hence the yield in sugar from boiled molasses cannot be very considerable if in curing the No. 1 sugar all the crystals were really separated from the molasses.

It often happens that during the cooling down of after-product masse-cuites, the surface becomes convex and eventually bursts, a brown froth oozing out of the crevices. This soon covers the whole surface, rising continually, and finally flowing over the brim of the cistern. Gases escape from this froth, emitting a very unpleasant smell and having an acid reaction, the whole phenomenon being called "froth-fermentation." With second and third molasses, where no hard crystalline crust is formed on the surface, the whole mass starts frothing from the bottom, but in other respects its aspect is quite the same as with the first molasses. A great deal has been said and written about this froth-fermentation, but a fully reliable remedy does not appear as yet to have been found. The fact is beyond doubt that it is, properly speaking, not a fermentation due to one or other minute organism, and hence all efforts to combat the phenomenon by means of disinfecting agents are fruitless. This froth-fermentation does not break up sugar, and as the masse-cuite is puffed up by disengaged gases, crystallization takes place very easily, hence such masse-cuites generally contain well-shaped crystals, and are very readily cured in centrifugals, for which reason it is customary to say that the froth changes into sugar, but this must not be taken literally. The most probable hypothesis is that the frothing is caused by the spontaneous decomposition of products arising from the breaking up of sugar or glucose, these products forming carbonic, formic, and acetic acids, humus and caramel, leaving unsettled the question whether sugar or glucose has been broken up by overheating or by the action of the alkalies.

The hypothesis appears plausible in view of the smell of the escaping gases, and of the further fact that this fermentation has been successfully obviated by steaming and skimming off the crude molasses. During this operation the glucinic acid in the acid molasses is broken up at the high temperature, by which means this product of decomposition is eliminated at once in the fluid molasses, and the fine crystals suspended in the molasses also become dissolved. If these are still present in the molasses at the time when the latter are drawn into the pan, they will settle on the steam coils, interfere with the conduction of heat, and finally, becoming overheated themselves, will give rise to troublesome products of decomposition. With a view to avoid decomposition it is therefore advisable not to allow the temperature in the pan to exceed 160° F.

A further proof for the thesis that froth-fermentation is to be ascribed to decomposition of products of superheating, is yielded by the fact that now the molasses are no more boiled repeatedly, but almost directly removed as exhausted and therefore run less risk of being superheated, the froth-fermentation of late years has occurred much less frequently than it used to do previously.

The reason why such masse-cuites only start frothing while cooling down, is explained by the fact that the unstable bodies break up spontaneously on the concentration of the solutions in which they are suspended. As a masse-cuite cools down, sugar crystallizes out, the result being that the impurities are accumulated in a more concentrated solution, and this promotes dissociation, which, when once started, goes on steadily in the hot medium. After the cooling is over it stops, and therefore the froth-fermentation is not so violent in small iron tanks, which cool down rapidly, as in large ones, where the heat is retained for a longer time. As has been already observed, no sugar is decomposed by this fermentation, and thus no chemical losses are to be feared, but the mechanical losses may be considerable when the mass foams over the edge of the tanks on to the floor. If this is prevented by only half filling them, the space disposable is not completely utilized, and the capacity of the plant at this stage is diminished.

All these form reasons enough for trying to prevent the fermentation, even though it does not attack the sucrose.

When the after-product masse-cuites are completely crystallized out, they, too, are separated into molasses and crystals. When the grain is large and the crystals do not stick to each other, this is effected by centrifugalling, but in case the grain is too minute, the masse-cuite is shovelled into bags made of mats, from which some molasses drain off, and the remaining mixture of about equal quantities of small sugar crystals and exhausted molasses, conglomerated into a sticky mass, is sold as "sack sugar," or "black stroop."

When the last masse-cuites are very sticky, presenting great hinderances to crystallization, this can be promoted by carefully pouring on them about a foot depth of water, and leaving them to stand for a month. A slow osmosis now takes place; the molasses become a little more fluid by taking up water, and at the same time a portion of the viscous salts diffuses into the water, whereby the quotient between glucose and ash rises, and accordingly the amount of crystallizing sugar is increased. In working up, the water is first removed and thrown away, and then the masse-cuite is packed in bags and the molasses allowed to drain off.

If the centrifugalled second boilings can be sold at a fair price, it is advisable to do so, but if they are only fetching a low price, or are quite unsaleable, then we are compelled to melt them over again in the juice, and to boil them into first sugar, which operation cannot be performed without loss, and in this case is unavoidable. The question now arises as to which stage of the manufacture is most suitable for this melting process. Some melt the second boilings in the heated mill juice, by allowing the latter to flow over a sieve on which this sugar is piled, as it comes out of the juice heater; others melt it in the subsided clarified juice, while others run off the syrup at a relatively low density and bring it to its proper concentration by dissolving the second sugar in it. All these methods have their defenders and their opponents. No loss in manufacturing is to be feared from dissolving these sugars in the syrup, but then the mistake is made of mixing the syrup that had been carefully clarified and neutralized with the (as a rule) acid sugars, and contaminating it with their impurities. We can only do this on condition that the syrup is afterwards thoroughly eliminated, neutralized, and allowed to settle. The same must be said with regard to melting the after-products in the clarified juice; in this case also an acid and impure body is dissolved in a clarified and neutralized juice, though this is preferable to melting the same sugars in the syrup, because they dissolve much more readily in the thin juice than in the already concentrated syrup. One drawback to this process is in the incrustation of the tubes of the triple-effect by the suspended impurities which settle on them during concentration.

From the point of view of obtaining a good clarification, the introduction of the seconds into the mill-juice is the more to be recommended, as they will then again be submitted to all the processes of clarification, against which may, however, be set the facts of the heavier juice subsiding slowly, and of the juice in the scum containing more sugar, so that more sugar is lost in the scum-cakes.

Another method is by dissolving the second-boilings in a little hot mill-juice to the concentration of syrup, skimming and neutralizing, and drawing it into the pan, in which a first-sugar masse-cuite is already half finished. The grain already formed in this is suspended in a liquid, the purity of which is in no way superior to that of the sugar solution just drawn in. In this way there is no loss in manufacturing, the juices are not spoiled by being mixed with inferior sugar, and no objection can be brought against drawing this solution into the pan, because the grain is already formed, which also would, under ordinary conditions, increase at the expense of a syrup which ultimately is no purer than the solution just drawn in. A good neutralization of this sugar solution is indispensable, as otherwise the acid molasses remaining between the crystals of the packed sugar might cause inversion and deterioration.

CHAPTER VII.

EXHAUSTED MOLASSES.

The syrupy liquid drained off from the first masse-cuite mixed with molasses or from the sack-sugar, from which practically no sugar crystals can be obtained by further boiling and cooling, is called exhausted molasses. It still contains, besides the accumulated impurities, whether originating from the cane juice or formed afterwards, a certain amount of sucrose which cannot be turned into any saleable product. The non-saccharine matters in any case require a certain quantity of water to remain in solution, and to allow of their being separated from the crystals, which water will, of course, also dissolve a greater or lesser quantity of sucrose, which hence becomes lost. Unless we succeed, during clarification, in eliminating all substances not sugar—a very improbable supposition—we shall always be sure to get molasses, and hence all processes claiming to make sugar without forming molasses must be considered *primâ facie* illusory. Good clarification and a carefully conducted rapid working up of the juice will do much to reduce the quantity of non-saccharine substances, and consequently also that of the molasses, but it is quite impossible to suppress these completely.

As we have already previously shown, the quantity of sugar remaining dissolved in the water of the molasses entirely depends on the mutual relation of the various non-saccharine bodies; a large proportion of glucose with a small amount of ash causes the molasses to be poor in sugar, whilst their sugar content rises, provided that the water remains the same, as soon as the quotient between glucose and ash falls. It is therefore advisable not to increase unnecessarily the amount of ash in the juice, especially that of the salts of organic acids, to which end a careful tempering is very necessary. The disadvantage of the increase of lime salts accompanying the carbonatation process is counterbalanced by the fact of this process eliminating half the non-saccharine matter, and thus also half the molasses-forming bodies. It should not be forgotten that not only the *percentage of sucrose*, but also the *quantity of the molasses formed* influences the loss of sugar, and that everything that contributes to diminishing the quantity of the molasses has a favourable effect on the output of sugar from the cane, even though the amount of sugar in the molasses may perhaps be a little increased.

If, for instance, juice having a quotient of 84 is worked up, delivering an exhausted molasses of 27 purity, the original juice contains 16% of non-sugar in 100 parts of dry substance. By the crystallizing of the sucrose, the quantity of non-sugar, the absolute amount of which may practically be considered as unchanged, is raised to 73 parts in 100 parts of dry substance in the molasses. The 100 parts of dry substance in the juice are at the same time reduced to $\frac{16 \times 100}{73}$ dry substance in molasses. As this contains 27 parts of sucrose on 100 parts of dry substance, the loss of sucrose in molasses on 100 parts of dry substance in juice has amounted to

$$\frac{16 \times 100 \times 27}{73 \times 100} = 8{\cdot}92\%.$$

If a juice of 92 purity had delivered a molasses of 35 quotient this loss of sucrose would have been

$$\frac{8 \times 100 \times 35}{65 \times 100} = 4{\cdot}31\%.$$

Hence we see, that notwithstanding the larger amount of sucrose in the molasses, the absolute quantity of sucrose lost is smaller in the second case.

It may happen that a very sticky molasses, having a high saccharine content, is already practically exhausted, because its nature does not admit of any further evaporation, as in such case the boiled mass would become too viscous to allow of crystallization.

In these cases the molasses contain so much gummy matter that one is obliged to leave much water in them, lest they should coagulate into a sticky mass of jelly after evaporation and cooling. If evaporation is actually carried on to this point, the crystallization is hindered, and the minute crystals can no longer be separated from the adhering sticky mother liquor, thus practically preventing them from being recovered.

If in order to avoid this the molasses are left less concentrated, too much sucrose remains dissolved and does not crystallize, for which reason the loss of sucrose in molasses is disproportionately heavy. Though the solubility of the sugar is in any case exclusively influenced by the proportion between glucose and ash, the quantity of water which we are compelled to leave in the molasses is regulated by the nature of the total amount of the non-saccharine bodies, because in practical working the masse-cuites have always to be boiled in such a way that a certain circulation remains possible. It is true that after higher concentration more sugar crystallizes, but this takes place in such a form that it cannot be separated. This accounts for the fact that in the table we find among the analyses of *exhausted* molasses one (No. 3) having 43·7 per cent. of sucrose, while a second molasses (No. 20), showing 22·42 per cent. of sucrose and a quotient of purity of 30·32, still yields a little sack-sugar after evaporation and cooling. From this it results that the chemical analysis cannot show with any reliability whether or not a molasses is to be considered as exhausted; while the amount of sucrose in exhausted molasses is very variable (varying between 35 and 45 per cent.), that of the total quantity of sucrose lost in molasses is tolerably constant, viz., from 5 to 7 per cent. of the sugar entering into the factory, in which calculation the molasses carried off along with the sugar crystals in the after-products is not included.

The accompanying tables, where analyses obtained from various methods of working are stated, may give some little idea of the composition of Java exhausted molasses. These molasses are not filtered mother-lyes as in Chapter VI., but technically exhausted molasses as they are removed from the factories. Some of them still contain minute grain, which enters into their composition, and accounts for the high readings for Brix met with in some instances.

I.—MOLASSES FROM FACTORIES WHICH DO NOT RETURN MOLASSES.

	Number.	Brix.	Polarization.	Quotient of Purity.	Glucose.	Ash.	Sulphate Ash.	Soluble Ash.	Insoluble Ash.	Iron Oxide, Alumina and Phosphoric Acid.	Lime.	Magnesia.	Potash.	Carbonic Acid in Ash.	Sulphuric Acid.	Chlorine.	Silica.	Gum.	Nitrogen.
CARBONATATION.	1	85·5	31·8	37·2	27·8	8·83	8·61	5·82	3·01	0·20	1·44	0·08	3·50	2·06	0·49	0·28	0·09	2·28	0·25
	2	81·4	31·0	38·1	24·0	9·76	9·34	7·38	2·38	0·38	1·03	0·02	3·76	1·25	0·74	0·28	0·14	0·60	..
	3	85·0	34·8	40·9	27·7	7·82	8·23	4·42	3·40	0·22	1·50	0·16	3·35	1·21	0·26	0·36	0·22	0·60	0·13
	4	85·8	30·6	35·7	20·9	11·87	11·37	7·24	4·63	0·21	2·39	0·06	4·47	2·93	0·57	0·62	0·09	3·29	0·21
DEFECATION.	5	77·0	34·6	45·0	21·8	9·13	9·19	7·08	2·05	0·61	0·42	0·16	4·67	1·01	0·61	1·12	0·37	1·11	..
	6	87·4	37·0	42·3	30·6	11·41	11·36	9·14	2·27	0·82	0·40	0·08	4·87	1·10	1·17	1·29	0·58	1·09	..
	7	82·8	35·8	43·2	18·6	8·91	8·84	6·99	1·92	0·54	0·47	0·09	4·30	1·05	1·53	0·84	0·36	1·33	0·23
	8	83·2	25·0	30·0	36·8	6·13	6·04	4·89	1·24	0·34	0·20	0·14	2·25	0·99	0·60	0·42	0·26	1·38	..
	9	79·8	29·2	36·6	27·9	8·42	8·47	6·01	2·41	0·45	0·81	0·12	3·48	1·75	0·82	0·22	0·32	1·90	..
	10	85·0	24·6	29·0	30·7	8·63	8·77	7·30	1·33	0·48	0·17	0·14	4·04	1·00	0·90	0·12	0·27	1·85	0·37
	11	82·8	34·0	41·0	21·8	9·35	9·30	6·67	2·68	0·26	1·23	0·08	4·11	1·41	0·68	0·98	0·15	1·77	..
	12	77·3	26·8	34·7	28·8	5·95	5·68	4·49	1·46	0·04	0·57	0·08	2·46	0·60	0·55	0·20	0·24	0·88	..

II.—MOLASSES FROM FACTORIES RETURNING MOLASSES AND MAKING 1ST AND 2ND SUGAR AND BLACK STROOP.

	Number.	Brix.	Polarization.	Quotient of Purity.	Glucose.	Ash.	Sulphate Ash.	Soluble Ash.	Insoluble Ash.	Iron Oxide, Alumina and Phosphoric Acid.	Lime.	Magnesia.	Potash.	Carbonic Acid in Ash.	Sulphuric Acid.	Chlorine.	Silica.	Gum.	Nitrogen.
Carbonatation.	13	85·2	30·8	36·1	24·0	10·62	10·74	8·22	2·40	0·22	1·12	0·04	4·92	2·40	0·28	0·50	0·11	1·74	. .
Defecation. .	14	86·0	25·4	29·5	31·7	7·85	7·90	6·35	1·50	0·40	0·30	0·09	4·06	1·18	1·74	0·51	0·37	2·20	0·18
	15	82·8	27·6	33·3	26·9	9·07	9·05	7·51	1·56	0·38	0·31	0·11	4·57	1·07	1·34	0·25	0·38	1·87	. .
	16	85·0	30·6	36·0	24·0	9·03	9·05	6·39	2·64	0·40	0·93	0·08	3·61	1·05	1·17	0·77	0·40	1·53	0·28
	17	84·0	31·0	36·9	32·8	7·23	7·21	4·68	2·55	0·59	0·75	0·13	2·26	0·97	0·90	0·77	0·34	1·53	. .
	18	84·2	36·4	43·2	24·5	7·54	8·17	4·72	2·82	0·80	0·59	0·17	2·68	1·22	0·38	0·57	0·62	1·90	0·13
	19	86·1	26·8	31·1	26·9	9·32	9·08	7·37	1·95	0·56	0·58	0·12	3·98	1·06	1·04	0·93	0·18	1·97	. .
	20	81·8	28·0	34·2	24·7	7·41	7·49	5·49	1·92	0·91	0·35	0·12	1·93	1·36	0·69	0·37	0·15	3·62	. .
	21	87·4	35·0	40·0	34·4	9·64	9·53	6·99	2·65	0·52	0·81	0·12	4·08	1·57	1·23	0·57	0·44	1·45	. .
	22	84·0	29·0	34·5	26·9	8·21	8·88	5·72	2·49	0·51	0·77	0·14	3·70	1·36	0·48	0·31	0·31	1·04	. .
	23	85·8	33·6	39·2	21·8	8·02	8·57	6·59	1·43	0·22	0·49	0·08	3·69	1·26	0·99	0·31	0·26	3·38	0·21

III.—MOLASSES FROM FACTORIES WHICH RETURN MOLASSES AND DELIVER FIRST SUGAR AND BLACK STROOP.

	Number.	Brix.	Polarization.	Quotient of Purity.	Glucose.	Ash.	Sulphate Ash.	Soluble Ash.	Insoluble Ash.	Iron Oxide, Alumina and Phosphoric Acid.	Lime.	Magnesia.	Potash.	Carbonic Acid in the Ash.	Sulphuric Acid.	Chlorine.	Silica.	Gum.	Nitrogen.
CARBONATATION.	24	83·0	29·0	35·0	31·6	7·82	8·09	5·04	2·78	0·21	1·29	0·06	2·80	1·71	0·32	0·76	0·15	0·68	0·08
	25	90·1	37·4	41·5	21·7	13·36	14·05	9·76	3·60	0·10	1·84	0·04	5·65	3·40	0·30	1·42	0·24	0·21	..
	26	86·1	28·0	32·5	19·6	11·66	11·02	4·99	6·67	0·18	3·54	0·04	3·08	3·35	0·47	0·53	0·08	0·91	0·20
	27	80·5	25·0	31·0	28·8	9·83	9·79	5·48	4·35	0·28	2·41	0·07	4·10	2·18	0·30	0·22	0·15	1·19	..
DEFECATION.	28	83·2	31·2	37·3	27·9	7·72	8·30	4·73	2·99	0·41	1·14	0·16	2·49	1·47	0·68	0·17	0·25	1·00	0·25
	29	84·0	30·6	35·2	30·7	6·79	7·46	5·42	1·37	0·52	0·24	0·04	3·86	1·01	0·69	0·16	0·34	1·37	..
	30	82·4	31·2	37·9	24·0	7·47	7·40	5·78	1·69	0·89	0·15	0·08	3·69	0·95	0·90	0·31	0·38	2·38	..
	31	85·8	27·6	32·2	25·7	9·92	9·70	7·33	2·59	0·30	0·77	0·10	4·16	1·39	1·31	0·71	0·52	1·48	..
	32	80·2	31·2	38·9	26·9	6·16	6·61	2·87	3·29	1·55	0·57	0·14	1·27	0·96	0·36	0·14	0·43	1·80	..
	33	76·8	28·2	36·7	27·9	8·34	8·42	5·88	2·46	0·24	0·99	0·05	2·83	1·16	0·76	0·42	0·35	1·29	..
	34	80·6	29·0	36·0	30·1	7·35	7·43	5·59	1·76	0·31	0·52	0·14	3·09	1·09	1·04	0·38	0·24	1·42	..
	35	76·6	28·2	36·8	21·8	8·36	8·87	6·07	2·29	0·79	0·60	0·11	3·60	1·65	0·29	0·34	0·20	6·26	0·08
	36	73·2	16·6	22·7	38·7	7·09	7·38	4·79	2·30	0·48	0·76	0·09	2·95	1·33	0·28	0·48	0·29	0·48	..
	37	79·4	35·4	44·6	26·8	6·21	6·06	4·95	1·26	0·74	0·10	0·05	3·28	0·88	0·56	0·44	0·25	5·94	0·35
	38	81·2	32·4	39·9	27·9	8·12	8·24	5·47	2·65	0·52	0·75	0·15	2·82	1·01	1·74	0·25	0·47	1·77	..

	Number.	Brix.	Polarization.	Quotient of Purity.	Glucose.	Ash.	Sulphate Ash.	Soluble Ash.	Insoluble Ash.	Iron Oxide, Alumina and Phosphoric Acid.	Lime.	Magnesia.	Potash.	Carbonic Acid in the Ash.	Sulphuric Acid.	Chlorine.	Silica.	Gum.	Nitrogen.
DEFECATION.	39	87·2	36·0	41·3	26·8	7·88	7·75	5·33	2·55	0·60	0·67	0·14	3·10	1·28	1·20	0·66	0·46	2·36	0·30
	40	83·0	32·0	38·6	28·8	6·21	6·33	5·26	0·95	0·33	0·21	0·09	3·98	0·67	0·37	0·52	0·15	1·39	..
	41	87·8	22·4	25·5	33·6	8·14	8·42	5·95	2·19	0·82	1·63	0·06	3·70	0·73	0·61	0·48	0·18	1·35	..
	42	88·0	37·6	42·7	30·1	6·69	7·71	4·64	2·05	0·67	0·26	0·15	2·69	0·46	0·98	0·43	0·58	1·72	..
	43	85·0	26·4	31·1	35·8	7·26	6·98	5·39	1·87	0·59	0·42	0·07	3·08	0·89	0·81	0·52	0·41	4·03	..
	44	86·7	29·0	33·5	32·9	8·58	8·29	6·47	2·11	0·24	0·80	0·17	2·98	0·66	1·18	0·61	0·28	5·55	0·25
	45	86·6	25·4	29·3	30·1	8·92	9·06	6·86	2·06	0·46	0·58	0·06	4·22	1·57	0·74	0·36	0·44	1·86	..
	46	85·2	28·0	32·9	27·9	8·56	9·33	6·05	2·51	0·51	0·91	0·12	3·67	1·30	1·03	0·47	0·25	1·32	..
	47	77·0	26·0	33·7	28·8	7·40	8·09	5·24	2·16	1·02	0·26	0·10	3·81	1·03	0·30	0·24	0·47	2·91	0·22
	48	86·0	27·8	32·3	24·7	9·60	10·07	7·43	2·17	0·46	0·61	0·10	4·44	1·60	0·88	0·12	0·41	1·38	..
	49	88·8	26·0	29·3	30·7	11·24	12·02	8·68	2·56	0·33	0·83	0·20	4·83	1·31	1·39	1·75	0·32	2·16	0·23

IV.—MOLASSES FROM A FACTORY DELIVERING ONLY FIRST SUGAR AND MOLASSES.

	50	88·8	29·0	32·7	34·4	9·20	9·47	6·09	3·11	0·86	0·67	0·18	4·19	0·98	1·44	0·72	0·69	2·35	..

As yet no satisfactory method of utilizing the molasses has been found. Osmosis has proved impracticable, as the impurities are doubtless so closely combined with the sugar that they do not diffuse any sooner than it does; and, further, the osmosis of cane sugar molasses goes on too slowly to give good results in practical working.

Experiments made in Java with newly invented methods of sugar extraction from molasses, which had proved successful with beet-molasses, failed. The high content of reducing sugar was an insurmountable obstacle. The quantity of molasses used for fodder is also too insignificant to deserve special mention.

The question of the use of molasses as fuel also presents difficulties, even when mixed with bagasse, for at low temperature it forms a voluminous mass of coal, which chokes up the grate, and at an elevated temperature the lime and alkali of the molasses combine with the silica from the bagasse, forming a kind of glass which covers the grate bars, and prevents the free access of air.

For very large factories it will pay to build a special molasses furnace, as is used in several cane-growing countries. This has no grate, the air enters under the fuel through holes made in the walls. The molasses is poured on an iron plate before the furnace, where it dries, and from whence it is shovelled into the furnace. The fire is started with a little fire-wood at the outset, and once being lit it is kept burning with the dried molasses. The combustion goes on perfectly, the ash is fine and well-nigh free from carbon. Its great advantage is its being very rich in potash, of which constituent it contains as much as 35%. Therefore it may be used by glassmakers, soapmakers, or as a fertilizer.

This is such an important item, that even if the quantity of molasses is too small to be able to feed a boiler regularly, it will pay to burn the molasses for the sake of its ash only.

Some estates use the molasses as a fertilizer, or in order to break up rocky subsoil. The molasses get sour and soften a hard subsoil, thus permitting its being tilled. In other places molasses are simply poured over the earth on the banks as manure. Selling the molasses to arrack distillers is perhaps the most economical way of disposing of them; fermenting and distilling them at the factory itself is not possible in Java, because of the prohibitive excise regulations.

The question of what to do with the molasses is therefore still an open one, and the only way many sugar manufacturers have of getting rid of this troublesome by-product is to throw it into the nearest stream.

PART III.

Chemicals used in Cane Sugar Manufacture.

1. *Lime.*

Lime being the only clarifying agent in cane sugar manufacture, it is evident that great care should be taken always to use the purest and best available, and it is better to spend a little more money to procure a pure brand than to use a cheap but impure lime, as the difference in expense is so trifling that it cannot enter into comparison with the heavy losses occasioned by the use of bad lime.

Factories working with the defecation process usually purchase the 600 or 700 cwts. of lime which they annually require; and only few of them burn it themselves from limestone or fossil coral in small kilns heated with wood. During this process the carbonate of lime, which forms the principal part of the limestone, becomes decomposed into quicklime, which remains in the kiln, and carbonic acid, which escapes. In factories using the carbonatation process, which requires large quantities of lime, it is burned in specially constructed furnaces with coke as fuel, and the gas passing off is utilized for saturation. In this case the limestone is broken into pieces, mixed with coke, and thrown in at the open end of the furnace, when the coke, in burning, forms carbonic acid, and by its heat decomposes the limestone into lime and carbonic acid. A suction pipe, fitted in the upper end of the furnace, and connected with a pump, draws off the carbonic acid, the resulting vacuum is again occupied by the air flowing in at the grate, by which means draught and combustion are maintained. Attention should be paid to prevent any holes in the furnace by which air can penetrate, other than the openings under the grate, as in this case the carbonic acid becomes diluted with air, and combustion is retarded. The gas drawn off from the furnace undergoes washing and cooling before being pumped off to the saturation tanks, because proper carbonatation requires a pure and cold carbonic acid in order to prevent any impurities being carried into the juice, and to keep the temperature from rising above 140° F.

From time to time the quicklime is removed from the furnace by a door under the grate, and allowed to cool, after which it is used in the factory as milk of lime. The best method of slaking lime is by pouring water over it in large brick tanks, and allowing both constituents to combine there, taking care to use a sufficient quantity of water for the slaked lime, after the action has ceased, to be covered by about an inch of water. This method is much better than allowing the lime to be slaked by the humidity of the atmosphere, because hard lumps remain unslaked, and, moreover, the lime also attracts carbonic acid from the air and becomes inactive, which is avoided by its being kept under water.

Before being used, the slaked lime is diluted with water to 20° Beaumé, strained through an iron strainer, and is then ready for use. The limestone selected should combine a high degree of purity with rapid combustion. The crystalline lime spars are very pure, but require a large amount of fuel, and therefore a soft limestone or fossil coral is to be preferred, if obtainable.

A description of a complete analysis of lime or limestone may be found in any handbook of analytical chemistry, but a rapid qualitative method for analyzing any kind of lime or limestone may perhaps not be out of place here.

Pour dilute hydrochloric acid on five grams of an average sample of the finely powdered limestone; this dissolves with emission of gas bubbles, leaving only a few flakes of insoluble matter. The filtered solution is boiled in order to drive off the carbonic acid, next, a few c.cm. of nitric acid are added, and the mixture rendered alkaline with ammonia. Iron oxide, alumina, silica, and phosphate of lime are thrown down (the total amount of these possibly also not exceeding a few flakes) which settle rapidly. Should the liquid become quite opaque, the limestone should be rejected.

Lime may be analyzed in the following way. Water being poured on five grams of the lime, the latter should swell, become hot, and quickly form a voluminous mass, which contains only a few or no hard particles. If the lime becomes slaked slowly or not at all, this may be in consequence of its not being burned enough, or being burned "dead" owing to too high a temperature or to impurities which have combined with it.

The moist slaked lime should dissolve completely and without effervescence in dilute hydrochloric acid. Effervescence indicates the presence of carbonic acid, it either not having been completely expelled or again attracted from the atmosphere; in case the lime dissolves slowly without effervescence it is burned dead, while sand, clay, and similar impurities remain undissolved. The solution is filtered, boiled, a few drops of nitric acid added, and then treated in the same way as described for the examination of limestone. If it is also decided to ascertain the presence of gypsum, a dilute solution of the lime or limestone in hydrochloric acid is tested with a solution of chloride of barium, which yields a white precipitate with the sulphate of the gypsum. For this test dilute solutions are required, as concentrated hydrochloric acid also precipitates barytes from its solutions, which precipitate, however, becomes dissolved on dilution, which the sulphate of barium does not.

As magnesia is a very troublesome constituent when occurring in lime used for clarification, it is advisable to examine every fresh parcel by the following quick method as to the magnesia contained.

One gram of the lime is dissolved in 10 c.cm. of hot water, adding by drops dilute hydrochloric acid until nearly all the lime is dissolved, the liquid being still neutral or slightly alkaline. If by accident this point has been passed, causing the acid reaction to predominate, a little more of the lime should be thrown in, in order to restore the neutral or alkaline reaction. The solution is next to be boiled and filtered, and ammonia added to the filtrate. If the lime is pure the filtrate remains clear, but if magnesia is present white gelatinous hydroxide falls down. Under the conditions here described, lime containing one per cent. of magnesia yields a distinct gelatinous separation. When the precipitate is more than just visible, the lime contains more than one per cent. of magnesia, and should not be used for clarification. Great care must be taken that the filtered liquid is not acid, because in that case, as has been shown above, the magnesia remains partially or entirely in solution after the ammonia has been added. The liquid should be boiled before filtering, to drive out all the carbonic acid, for if the latter remained in the liquid, it would form carbonate of ammonia, which precipitates carbonate of lime, and thus might cause us to assume the presence of magnesia, even in pure lime.

In testing for magnesia in limestone, two grams of the finely-powdered stone are boiled with 10 c.cm. of water and so much dilute hydrochloric acid, that the liquid shall be neutral and contain only a very small quantity of the stone still unaffected by the acid; a few c.cm. of lime water are added to throw down oxide of iron and alumina, which are occasionally present; the mixture is then filtered and the filtrate treated with ammonia.

In doubtful cases the test with phosphate of soda after the removal of the lime by oxalate of ammonia is, of course, to be preferred, but if it is desired to ascertain very quickly whether a parcel of lime or limestone may be used, the above described tests will render good service.

2. *Phosphoric Acid.*

The phosphoric acid used in sugar manufacture is met with in commerce either as free acid in solution or as a paste in the form of acid phosphate of lime. The first generally contains 35 to 40% of free anhydrous phosphoric acid and scarcely any acid in combination, while the acid phosphate contains 25 to 30% of free acid and about 10% of acid neutralized by lime. The amount of free acid is easily determined by titration with normal test solution of soda, in which case it should be borne in mind that, using phenolphthalein as an indicator, every c.cm. of the test solution neutralizes 35·5 mgr. of P_2O_5. Both preparations should also be tested for sulphuric acid, the amount of which should be as small as possible, as the gypsum dissolves in the juice and deposits itself on the tubes of the evaporators in the form of a hard incrustation.

Both the free acid and the acid salt may be used, though for the purpose of neutralization the pure acid is to be preferred, while the acid lime salt, on the contrary, is preferable in cases where a heavy precipitate is wanted to cause subsidence of a juice that does not easily settle, as with the same quantity of acid more precipitate is thrown down by the acid lime salt than by the pure acid. If necessary, both preparations can be made in the factory itself from the double superphosphate commonly used for manuring, which is much better material for making it than bones and sulphuric acid.

When making the acid lime salt, the double superphosphate is extracted with as little water as possible, to prevent the gypsum from becoming dissolved, and the solution is then diluted to the proper density.

By boiling the concentrated solution with the calculated quantity of sulphuric acid, and allowing the gypsum to crystallize, the free acid can be prepared, but this operation is too troublesome to be performed in a sugar factory, and should be left to the chemical manufacturer.

3. *Sulphurous Acid.*

The best way of making sulphurous acid is by burning sulphur in an iron oven, allowing free access of air. Either air may be conducted over the burning sulphur, or a steam jet may be applied in the chimney by which the vapours pass off, which causes a current of fresh air to pass over the burning sulphur. The sulphurous acid is cooled by a stream of cold water flowing round the escape pipe; it then runs through lead or cast-iron tubes, and is admitted into the saturation tanks by lead pipes, opened or closed by india-rubber check-valves.

In order to prevent formation of sulphuric acid during the combustion, the air that passes over the sulphur should be previously dried, for if it be moist, sulphuric acid is produced, which quickly corrodes the iron oven or the tubes. This drying is effected by compelling the air to pass through a long box or tube, filled with quicklime. When the sulphurous acid is once formed it may be drawn off by a steam injector without fear of further oxidation. How dangerous it is to burn the sulphur in moist air may be seen from an analysis of incrustations found in a sulphur oven, which had only been a fortnight in use, and into which moist air had been introduced for burning the sulphur:—

Sulphate of iron	68·30
Sulphuret of iron	1·10
Free sulphuric acid	1·25
Sulphur	20·77
Insoluble in hydrochl. acid	1·26
Water	6·64
Undetermined	0·68
	100·00

PART IV.

TABLES.

1. Formula and Table for adjusting the Bagasse Turner for Three Roller Mills, having Rollers of 26 in. to 32 in. diameter.

When the position of the rollers has been settled, so that they will crush the quantity of cane corresponding with the capacity of the factory, the proper adjusting of the bagasse turner may be determined, which should properly be curved in a logarithmical spiral, for which may be substituted an arc of a circle, owing to the relatively small length of the turner. The construction of this is made easy by the following table, in which—

R = radius of the circle of which the trash turner is an arc.
S = distance between head and feed rollers.
D = diameter of the rollers.
Angle a = constant angle of spiral.

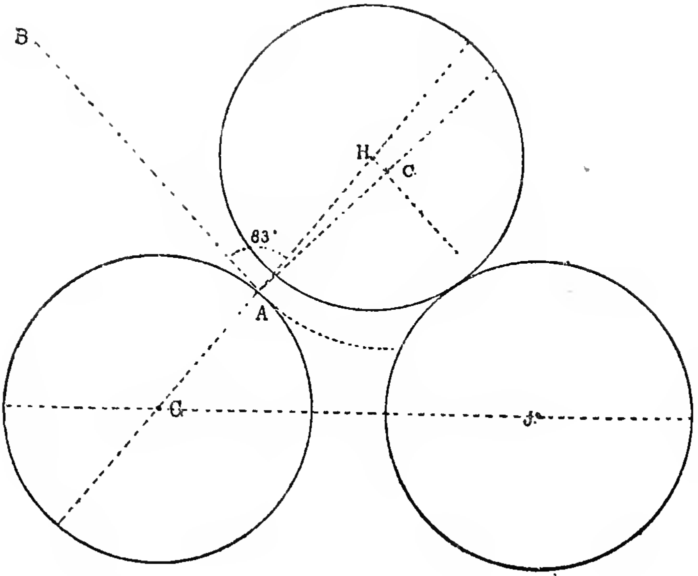
For a Distance S of 2 to 4 Inches.

D. Diameter of the Rollers in inches.	D. Diameter of the Rollers in mm.	Angle a.	R. In Inches.	R. In mm.
26	660	83° — 81°	$13\frac{10}{16}$ — $13\frac{14}{16}$	345 — 352
27	686	83° — 81°	$14\frac{3}{16}$ — $14\frac{6}{16}$	360 — 365
28	712	83° 30′ — 81° 30′	$14\frac{10}{16}$ — $14\frac{15}{16}$	370 — 378
29	738	83° 30′ — 81° 30′	$15\frac{3}{16}$ — $15\frac{8}{16}$	385 — 392
30	762	84° — 82°	$15\frac{10}{16}$ — $15\frac{15}{16}$	395 — 404
31	788	84° — 82°	$16\frac{2}{16}$ — $16\frac{6}{16}$	409 — 416
32	814	84° 30′ — 83°	$16\frac{11}{16}$ — 17	423 — 430

In this table the greatest angles concur with the lowest values for S, and the lowest figures for R with the lowest for S.

The construction is effected as follows:—

Draw the exact position of the rollers to scale, join the centres of the head and feed rollers, draw the angle a (generally = 83°), beginning at the point A, causing angle H A B to be 83°. Now draw A C perpendicular to A B and H C perpendicular to A C, when C will be the centre of the circle, having the radius A C = R, of which the trash turner is an arc.



2. *Table showing the Solubility of Sucrose in Water, from 0° to 100°, according to A. Herzfeld.**

Temp.	Per cent. of Sucrose.	Temp.	Per cent. of Sucrose.	Temp.	Per cent. of Sucrose.
0	64·18	20	67·09	40	70·42
1	64·30	21	67·25	41	70·60
2	64·45	22	67·41	42	70·78
3	64·59	23	67·57	43	70·96
4	64·73	24	67·73	44	71·14
5	64·87	25	67·89	45	71·32
6	65·01	26	68·05	46	71·50
7	65·15	27	68·21	47	71·68
8	65·29	28	68·37	48	71·87
9	65·43	29	68·53	49	72·06
10	65·58	30	68·70	50	72·25
11	65·73	31	68·87	51	72·44
12	65·88	32	69·04	52	72·63
13	66·03	33	69·21	53	72·82
14	66·18	34	69·38	54	73·01
15	66·33	35	69·55	55	73·20
16	66·48	36	69·72	56	73·39
17	66·63	37	69·89	57	73·58
18	66·78	38	70·06	58	73·78
19	66·93	39	70·24	59	73·98

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* Zeitschrift f. d. Rübenzuckerindustrie, 1892, page 181.

Table showing the Solubility of Sucrose in Water, from 0° to 100°, acccording to A. Herzfeld.—Continued.

Temp.	Per cent. of Sucrose.	Temp.	Per cent. of Sucrose.	Temp.	Per cent. of Sucrose.
60	74·18	74	77·06	88	80·15
61	74·38	75	77·27	89	80·38
62	74·58	76	77·48	90	80·61
63	74·78	77	77·70	91	80·84
64	74·98	78	77·92	92	81·07
65	75·18	79	78·14	93	81·30
66	75·38	80	78·36	94	81·53
67	75·59	81	78·58	95	81·77
68	75·80	82	78·80	96	82·01
69	76·01	83	79·02	97	82·25
70	76·22	84	79·24	98	82·49
71	76·43	85	79·46	99	82·73
72	76·64	86	79·69	100	82·79
73	76·85	87	79·92		

General formula for the solubility: $y = 64{\cdot}1835 \times 0{\cdot}13477\,x \times 0{\cdot}0005307\,x^2$. y = per cent. of sugar and x = temp. in degrees C.

3. Table showing the Specific Gravity of Milk of Lime according to Lunge and Blattner.

Degrees Beaumé.	Grams of CaO in 1 Litre.	Weight of 1 Litre of Milk of Lime. Gr.	Degrees Beaumé.	Grams of CaO in 1 Litre.	Weight of 1 Litre of Milk of Lime. Gr.
1	7·5	1007	16	159	1125
2	16·5	1014	17	170	1134
3	26	1022	18	181	1142
4	36	1029	19	193	1152
5	46	1037	20	206	1162
6	56	1045	21	218	1171
7	65	1052	22	229	1180
8	75	1060	23	242	1190
9	84	1067	24	255	1200
10	94	1075	25	268	1210
11	104	1083	26	281	1220
12	115	1091	27	295	1231
13	126	1110	28	309	1241
14	137	1108	29	324	1252
15	148	1116	30	339	1263

4. *Specific Gravity of Soda Solutions at 28° C. (82·4° F.)*

Percentage of Soda.	Specific gravity of a percentage of	
	Na_2O.	NaOH.
1	1·012	1·009
2	1·027	1·020
3	1·040	1·032
4	1·055	1·043
5	1·071	1·056
6	1·086	1·067
7	1·111	1·078
8	1·116	1·089
9	1·129	1·100
10	1·142	1·112
11	1·158	1·123
12	1·172	1·133
13	1·187	1·145
14	1·200	1·156
15	1·215	1·167
16	1·230	1·178
17	1·241	1·184
18	1·254	1·198
19	1·266	1·209
20	1·281	1·221
21	1·269	1·234
22	1·311	1·243
23	1·325	1·254
24	1·337	1·265
25	1·351	1·275
26	1·365	1·286
27	1·374	1·296
28	1·391	1·306
29	1·416	1·317
30	1·420	1·328
31	1·434	1·339
32	1·446	1·347
33	1·458	1·359
34	1·471	1·370
35	1·484	1·380
36	1·496	1·391
37	1·511	1·401
38	1·526	1·411
39	1·539	1·422
40	1·554	1·433
41	1·566	1·443
42	1·579	1·452
43	1·593	1·464
44	1·606	1·474
45	1·617	1·484
46	1·632	1·495
47	1·645	1·503
48	1·658	1·514
49	1·673	1·524
50	1·685	1·535
51	1·700	1·545
52	1·714	1·555
53	1·725	1·565
54	1·740	1·575
55	1·755	1·586
56	1·770	1·596
57	1·780	1·606
58	1·795	1·617
59	1·810	1·628
60	1·825	1·638

It is self-evident that the above figures are only exact for solutions containing only the substances mentioned, hence only for pure solutions.

5. *Specific Gravity of Solution of Carbonate of Soda at 28° C. (82·5° F.) according to Schiff.*

Specific gravity.	Percentage of the Solution of	
	Na_2CO_3. 10 H_2O.	Na_2CO_3.
1·0038	1	0·370
1·0076	2	0·741
1·0114	3	1·112
1·0153	4	1·482
1·0191	5	1·853
1·0231	6	2·223
1·0270	7	2·594
1·0309	8	2·965

Specific Gravity of Solution of Carbonate of Soda at 28° C. (82·5° F.) according to Schiff.—Continued.

Specific gravity.	Percentage of the Solution of Na_2CO_3. 10 H_2O.	Percentage of the Solution of Na_2CO_3.	Specific gravity.	Percentage of the Solution of Na_2O_3. 10 H_2O.	Percentage of the Solution of Na_2CO_3.
1·0348	9	3·335	1·1200	30	11·118
1·0388	10	3·706	1·1242	31	11·488
1·0428	11	4·076	1·1284	32	11·859
1·0468	12	4·447	1·1326	33	12·230
1·0508	13	4·817	1·1368	34	12·600
1·0548	14	5·188	1·1410	35	12·971
1·0588	15	5·558	1·1452	36	13·341
1·0628	16	5·929	1·1494	37	13·712
1·0668	17	6·299	1·1536	38	14·082
1·0708	18	6·670	1·1578	39	14·453
1·0748	19	7·041	1·1620	40	14·824
1·0789	20	7·412	1·1662	41	15·195
1·0830	21	7·782	1·1704	42	15·566
1·0871	22	8·153	1·1746	43	15·936
1·0912	23	8·523	1·1788	44	16·307
1·0953	24	8·894	1·1830	45	16·677
1·0994	25	9·264	1·1873	46	17·048
1·1035	26	9·635	1·1916	47	17·418
1·1076	27	10·005	1·1959	48	17·789
1·1117	28	10·376	1·2002	49	18·159
1·1158	29	10·746	1·2045	50	18·530

6. *Specific Gravity of pure Solution of Phosphoric Acid at 28° C. (82·5° F.)*

Specific Gravity.	Percentage of the Solution of H_3PO_4.	Percentage of the Solution of P_2O_9.	Specific Gravity.	Percentage of the Solution of H_3PO_4.	Percentage of the Solution of P_2O_5.
1·0024	1	0·726	1·0781	14	10·164
1·0079	2	1·452	1·0844	15	10·890
1·0134	3	2·178	1·0907	16	11·616
1·0190	4	2·904	1·0970	17	12·342
1·0246	5	3·630	1·1032	18	13·068
1·0303	6	4·356	1·1097	19	13·794
1·0360	7	5·082	1·1163	20	14·520
1·0419	8	5·808	1·1208	21	15·246
1·0478	9	6·534	1·1296	22	15·972
1·0537	10	7·260	1·1364	23	16·698
1·0597	11	7·986	1·1432	24	17·424
1·0658	12	8·712	1·1501	25	18·150
1·0719	13	9·438	1·1571	26	18·876

Specific Gravity of pure Solution of Phosphoric Acid at 28° C. (82·5° F.)—Continued.

Specific Gravity.	Percentage of the Solution of		Specific Gravity.	Percentage of the Solution of	
	H_3PO_4.	P_2O_5.		H_3PO_4.	P_2O_5.
1·1641	27	19·602	1·2936	44	31·944
1·1712	28	20·328	1·3018	45	32·670
1·1784	29	21·054	1·3102	46	33·496
1·1856	30	21·780	1·3186	47	34·222
1·1928	31	22·506	1·3273	48	34·948
1·2000	32	23·232	1·3358	49	35·674
1·2073	33	23·958	1·3445	50	36·400
1·2148	34	24·664	1·3532	51	37·126
1·2224	35	25·410	1·3620	52	37·852
1·2298	36	26·136	1·3718	53	38·578
1·2375	37	26·862	1·3808	54	39·304
1·2453	38	27·588	1·3899	55	40·030
1·2532	39	28·314	1·3980	56	40·756
1·2611	40	29·040	1·4072	57	41·482
1·2698	41	29·766	1·4165	58	42·208
1·2772	42	30·492	1·4259	59	42·934
1·2854	43	31·218	1·4353	60	43·660

7. *Relation between degrees Celsius and Fahrenheit.*

N degrees C. $= 32 + \frac{9}{5}$ degrees F.

N degrees F. $= \frac{5}{9}$ (N$-$32) degrees C.

C.	F.	C.	F.	C.	F.	C.	F.
0	32·	15	59·	30	86·	45	113·
1	33·8	16	60·8	31	87·8	46	114·8
2	35·6	17	62·6	32	89·6	47	116·6
3	37·4	18	64·4	33	91·4	48	118·4
4	39·2	19	66·2	34	93·2	49	120·2
5	41·	20	68·	35	95·	50	122·
6	42·8	21	69·8	36	96·8	51	123·8
7	44·6	22	71·6	37	98·6	52	125·6
8	46·4	23	73·4	38	100·4	53	127·4
9	48·2	24	75·2	39	102·2	54	129·2
10	50·	25	77·	40	104·	55	131·
11	51·8	26	78·8	41	105·8	56	132·8
12	53·6	27	80·6	42	107·6	57	134·6
13	55·4	28	82·4	43	109·4	58	136·4
14	57·2	29	84·2	44	111·2	59	138·2

Relation between degrees Celsius and Fahrenheit.—Continued.

C.	F.	C.	F.	C.	F.	C.	F.
60	140·	71	159·8	82	179·6	93	199·4
61	141·8	72	161·6	83	181·4	94	201·2
62	143·6	73	163·4	84	183·2	95	203·
63	145·4	74	165·2	85	185·	96	204·8
64	147·2	75	167·	86	186·8	97	206·6
65	149·	76	168·8	87	188·6	98	208·4
66	150·8	77	170·6	88	190·4	99	210·2
67	152·6	78	172·4	89	192·2	100	212·
68	154·4	79	174·2	90	194·		
69	156·2	80	176·	91	195·8		
70	158·	81	177·8	92	197·6		

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